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Geographic patterns in the demersal ichthyofauna of the Aleutian Islands

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ABSTRACT

The goal of this research was to investigate geographic patterns in the Aleutian Island region's demersal ichthyofauna and to determine whether they reflected the physical and biological oceanographic patterns documented by other authors in this volume. The analyses were structured according to the level of organization: at the community level patterns in species occurrence and community structure were investigated; at the population level distribution and abundance were examined; at the individual level food habits and growth were studied. There were step-changes in species occurrence, diversity, population distribution and food habits at Samalga Pass and at sites farther west. These longitudinal trends indicated physical and biological variation along the length of the Aleutian Islands chain, however depth-related patterns were as common as longitudinal patterns in demersal fish distribution. In addition, high catches of patchily distributed species occurred in areas expected to be biological "hot spots" due to increased productivity and prey availability. These patterns suggest linkages between demersal fish ecology and the biophysical processes described by other authors in this volume and indicate that inter-disciplinary research is needed to elucidate the underlying mechanisms.

Key words: Aleutian Islands, cluster analysis, demersal fish, distribution, food habits, geographic patterns, groundfish, growth, species diversity.

INTRODUCTION

The Aleutian Islands region is a unique ecosystem. Formed by the peaks of the Aleutian ridge, it is the world's only longitudinally oriented, high-latitude island archipelago. It is also unique in its great length (1800 km). Befitting a partially submerged mountain range, the shelf along the Aleutian Islands is narrow and the continental slope is steep. The primary currents in the region are the Alaska Coastal Current and the Alaskan Stream to the south, and the Aleutian North Slope Current to the north. The Aleutian passes are conduits through which the North Pacific and the Bering Sea interact through tidal currents and mixing. The result of the interaction between currents, passes and bathymetry is a spatially and temporally complex ocean environment (Coyle, 2005; Ladd *et al.*, 2005a; Mordy *et al.*, 2005; Stabeno *et al.*, 2005). Much of the island chain is undeveloped and provides important habitat for fish, seabirds (Jahncke *et al.*, 2005; Byrd *et al.*, 2005) and marine mammals (Sinclair *et al.*, in review; Call and Loughlin, 2005).

Demersal fishes of the Aleutian Islands are important economically and ecologically. The commercial catch of demersal fish in 2003 in the Bering Sea/Aleutian Islands totaled 1.9 million metric tons worth an ex-vessel value of $481 million (Hiatt *et al.*, 2004). Walleye pollock (*Theragra chalcogramma*) is the dominant species of the commercial catch in the Bering Sea/Aleutian Islands (63% of the total ex-vessel value in 2003), followed by Pacific cod (*Gadus macrocephalus*), flatfishes (Pleuronectidae), sablefish (*Anoplopoma fimbria*), Atka mackerel (*Pleurogrammus monopterygius*), and rockfishes (*Sebastes* and *Sebastolobus spp.*) (Hiatt *et al.*, 2004). In addition to their commercial value, demersal fishes play important ecological roles as both predators and prey in the Aleutian Islands region. Piscivorous species include Pacific cod and arrowtooth flounder (*Atheresthes stomias*), which consume other demersal fishes (primarily Atka mackerel and walleye pollock) and myctophids (Yang, 2003). Planktivores include Atka mackerel, walleye pollock and several species of rockfishes (Yang, 2003). Demersal fishes are prey for upper trophic level predators such as marine mammals. For example, walleye pollock and Atka mackerel are the most common prey of Steller sea lions (*Eumetopias jubatus*) in western Alaska, followed by salmonids and Pacific cod (Sinclair and Zeppelin, 2002).

Geographic patterns in the demersal fish communities of the Gulf of Alaska and the eastern Bering Sea have been well studied. For instance, geographic patterns in species occurrence and community structure of demersal fishes in the Gulf of Alaska have been documented (Mueter and Norcross, 1999; 2002). Relationships between fish distribution and environmental characteristics, such as depth, temperature, bathymetry and bottom substrate type, have been investigated in both systems (OCSEAP, 1986; Bailey *et al.*, 1999; Krieger and Ito, 1999; Wyllie-Echeverria and Ohtani, 1999; Mueter and Norcross, 2000; McConnaughey and Smith, 2000; Abookire *et al.*, 2001; Brodeur, 2001; Mueter and Norcross, 2002; Bailey *et al.*, 2003; Duffy-Anderson *et al.*, 2003). There has also been extensive study of the distribution, abundance, feeding and growth of juvenile fishes, primarily age-0 walleye pollock, in the Gulf and Bering Sea (Mueter and Norcross, 1994; Brodeur *et al.*, 2000; Wilson, 2000; Brodeur *et al.*, 2002; Ciannelli *et al.*, 2002). Finally, the food habits of Gulf of Alaska and eastern Bering Sea demersal fishes are well-documented (Mito *et al.*, 1999; Yang and Nelson, 2000; Lang *et al.*, 2003).

In contrast to other Alaska ecosystems, very little is known about the ecology of the demersal fish community of the Aleutian Islands region. The food habits of demersal fishes have been summarized for the region as a whole (Yang, 1999; 2003), and geographic trends in Atka mackerel growth have been documented (Lowe *et al.*, 1998). In contrast to the extensive literature for the Gulf of Alaska and eastern Bering Sea, there are no published studies on geographic patterns in Aleutian demersal fish species occurrence, community structure, distribution and abundance. Neither have spatial patterns in food habits within the Aleutian Islands been investigated.

The goal of this research was to investigate geographic patterns in the demersal ichthyofauna of the Aleutian Islands and to determine whether the patterns we found reflected those in the physical and biological oceanography documented by other authors in this volume (Coyle, 2005; Ladd *et al.*, 2005a and b; Mordy *et al.*, 2005; Stabeno *et al.*, 2005). We structured our inquiries according to the level of organization from the community down to the individual. At the community level we investigated geographic patterns in species occurrence and community structure. At the population level we examined fish distribution and abundance. At the individual level we studied geographic patterns in food habits and growth.

METHODS

Bottom trawl surveys

The Alaska Fisheries Science Center (AFSC) of the National Marine Fisheries Service (NMFS) conducted bottom trawl surveys to collect standardized data on the distribution, abundance and biological condition of Alaska groundfish stocks. The Aleutian Islands bottom trawl surveys covered depths to 500 m along the north side of the island chain from Unimak Pass (165EW) westward to the Islands of Four Mountains/Samalga Pass (170EW) and on both sides of the chain from Islands of Four Mountains/Samalga Pass to Stalemate Bank (170EE) (Harrison, 1993). The area south of the chain from Unimak Pass to the Islands of Four Mountains/Samalga Pass was surveyed during the Gulf of Alaska survey (Britt and Martin, 2001). The Gulf of Alaska survey extended east to Dixon Entrance (132° 40' W), covering the continental shelf and upper continental slope to 1000 m depth. Surveys in the Aleutian Islands were conducted in 1980, 1983, 1986, 1991, 1994, 1997, 2000 and 2002. Surveys in the Gulf of Alaska were conducted in 1984, 1987, 1990, 1993, 1996, 1999, 2001, and 2003. Surveys were conducted during summer beginning as early as May and ending as late as September. Survey durations were approximately 140 days.

A stratified random sampling design was employed during both surveys (Harrison, 1993; Britt and Martin, 2001). The Aleutian Islands survey region was divided by North Pacific Fishery Management Council (NPFMC) regulatory areas (Fig. 1) which were further divided into 45 area-depth strata to a depth of 500 m. The Gulf of Alaska survey region was divided into 59 strata categorized by water depth, type of geographical area and NPFMC regulatory areas. The stratified random design greatly facilitated the collection of data on the distribution and abundance of groundfishes in the Aleutian Islands, but the data are nonetheless restricted to trawlable areas such that there is limited information on the distribution and abundance of fishes in very rocky or steep habitat.

Data on catch weight by species were collected from each haul. All fishes were identified to species whenever possible. Additional biological data were collected on species selected due to their commercial value or high abundance. A random subsample of these fish was sorted by sex, and individual fork lengths (FL) and wet weights were measured. Age structures (otoliths, scales, or both) were also collected. Stomach samples from selected species were collected during the surveys.

Biomass estimates were calculated using the area-swept method (Alverson and Pereyra, 1969). For each species, catch-per-unit-effort (CPUE) was calculated for each tow by dividing catch weight (kg) by the area swept by the tow (km^2). A mean CPUE for each stratum was calculated as the mean of the individual tow CPUE (including zero catches) within that stratum. Biomass estimates were calculated by multiplying each stratum mean CPUE by the stratum area (Harrison, 1993; Britt and Martin, 2001).

Analyses described in this paper were restricted to survey data collected from 1990 to 2002 because most survey effort prior to 1990 was conducted with non-standard survey gear and without rigorous fishing effort measurements. Exceptions are the analyses of diet composition and growth. The diet composition analysis utilized the entire data set because the non-standard trawl survey methodology was not expected to affect groundfish stomach contents data. The diet composition analysis also utilized stomach samples obtained by fishery observers during commercial fishing operations from 1982 to 1999. The growth analysis was restricted to the 1997 and 2000 data, years during which sufficient sample sizes of fish otoliths by subarea were collected.

Many of the results presented in this paper were based on survey catch or biological data averaged over several years' surveys and thus interannual and seasonal patterns were not examined. The broad temporal scale of our analyses also likely resulted in the loss of information on fine-scale spatial patterns. This approach was appropriate because our goal was to examine geographic trends in the Aleutian Islands ichthyofauna at a broad scale.

Species occurrence

The distributions of demersal fish species in the Aleutian Islands region were examined using published records (Allen and Smith, 1988; Sheiko and Federov, 2000; Mecklenburg *et al.*, 2002) and vouchered records in the AFSC Aleutian Islands and Gulf of Alaska bottom trawl survey database. Species with distributions that were continuous across the Aleutian chain were eliminated, because these species would be less informative regarding the influence of Aleutian passes on demersal fish distributions at the community level. Many commercially important species, such as Pacific ocean perch (*Sebastes alutus*), walleye pollock, Pacific cod and Atka mackerel were thus not included in this analysis, but were considered individually in later sections of this paper. Species that were not consistently identified or were inadequately sampled during AFSC bottom trawl surveys due to habit or habitat (e.g. semi-demersal or deeper than 500 m) were also eliminated.

The Aleutian Islands area was divided into six regions, defined by the following passes: Unimak, Samalga, Amukta, Tanaga, Amchitka and Buldir (the unnamed pass between Buldir and Semichi Islands; Fig. 2). Species that occurred in each region were then listed, and the total number of species in each region was summed. All species were classified by biogeographical province (Allen and Smith, 1988) and considered to be members of the Aleutian province. Species were further grouped according to their biogeographical affinities outside of the Aleutian province following the criteria of Allen and Smith (1988). The goal of grouping species in this way was to assess the broader scale distribution of species found in the Aleutians and to gain some insight into patterns of distribution at the evolutionary scale. The provinces of interest (outside the Aleutian province) were: Arctic-Kurile, which included species found in both Arctic and Kurile provinces, ranging from north of the Bering Strait into the western Bering Sea; Kurile, species found in the western Pacific whose range may include the western Bering Sea, Kurile Islands and Commander Islands; and Oregonian, species found in Southeast Alaska and Canada (Fig. 2).

Community structure

Cluster analyses were conducted to identify co-occurring groups of demersal fish species and their geographic and depth distributions. Analyses were carried out at two different scales of resolution with regard to the numbers of species included: a community-wide resolution and a “rockfish-specific” resolution. The purpose of the community-wide analysis was to identify broad-scale species associations and to examine differences in distribution among clusters of species. The original motivation for the “rockfish-specific” analysis was to assess the co-occurrence of rockfish with commercially important species (Pacific cod, Atka mackerel and sablefish) so that the effects of management regulations to limit rockfish bycatch could be better understood. Our purpose in presenting the results here is to examine the geographic distribution of assemblages of species within which rockfish occur.

Abundance matrices were first assembled from AFSC Aleutian Islands bottom trawl survey data. The matrix for the community analysis was constructed from the computed mean biomass by strata for 43 species, that were selected based on criteria of good catchability by trawls and consistent identification by survey personnel. The community matrix was constructed by strata to describe differences in the general community structure across the Aleutian Islands at a gross scale. The matrix for the rockfish analysis was based on CPUE by haul for several rockfish species (plus Pacific cod, Atka mackerel and sablefish). The rockfish matrix was constructed by haul because the intent of this matrix was to examine rockfish community structure at a finer scale and also how the three major commercial species in the Aleutian Islands region associate with rockfish species.

Cluster analyses were then conducted on dissimilarity matrices calculated from the two abundance matrices (Logen *et al.*, 1980). The community clustering analysis employed an agglomerative cluster analysis as per Van Tongeren (1995) using the S-Plus complete linkage clustering method (Insightful Corporation, 2001). Of the various cluster analysis methods the complete linkage method is most useful to highlight differences between clusters because it is biased towards overestimation of differences between clusters. This method is appropriate for the community level analysis because community structure may have been blurred due to averaging of species biomass over inter-annual variability. Initially (at step 0), each stratum is considered as a separate cluster (Insightful Corporation, 2001). The rest of the computation consists of iteration of the following steps: first, merge the two clusters with smallest between-cluster dissimilarity (R), and second, compute the dissimilarity between the new cluster and all remaining clusters (Q). The between-cluster dissimilarity is defined as:

$$d(R,Q) = \max_{i \in R,\, j \in Q} d(i,j) \qquad [1]$$

where R and Q represent clusters of merged strata and where i and j are the strata within R and Q. Thus, the dissimilarity between two clusters $d(Q,R)$ is given by the maximum dissimilarity between any pair of strata $d(i,j)$ of the clusters.

The rockfish analysis used the average linkage clustering method which is widely used in ecology (Van Tongeren, 1995). Average linkage clustering uses the average dissimilarity measure distances between all possible pairs of points within the two clusters. Those clusters with the smallest average distance between their points are then merged at each step of the clustering analysis. This method was selected for the rockfish community analysis because the goal of this analysis was to identify groups of hauls that were on average most similar, as opposed to most different. In contrast to the complete linkage method which groups species that are most dissimilar, the average linkage method groups species that are on average more similar to other members of that cluster than to members of any other cluster. In the average linkage method, average dissimilarity d(r,s) is computed as:

$$d(r,s) = \frac{T_{rs}}{N_r \times N_s} \qquad [2]$$

where T_{rs} is the sum of all pairwise distances between cluster r and cluster s. N_r and N_s are the sizes of the clusters r and s respectively**.** At each stage of hierarchical clustering, the clusters r and s, for which d(r,s) is the minimum, are merged.

Distribution and abundance

The distribution and abundance of four major commercial groundfish species in the Bering Sea and Aleutian Islands were examined: walleye pollock, Pacific cod, Atka mackerel, and Pacific ocean perch. The survey area was broken into intervals of ¼ degree longitude and 100 m depth ranges. The number of hauls in each interval and the mean CPUE for those hauls was computed. These mean CPUEs were used as an indicator of fine-scale spatial patterns in abundance. This analysis pools data over several different years and does not account for interannual variability in fish density or distribution; the goal was to identify spatial patterns that persist over time. Because of this temporal pooling, the CPUE figures should be considered as relative measures only. CPUE data for all four species, and especially for Atka mackerel and Pacific ocean perch, were strongly skewed with a large proportion of zeroes. New statistical methods are currently being developed at AFSC that will improve abundance estimates from these highly skewed data, but they are not available for the present analysis.

Food habits

Feeding habits of common demersal fish species were assessed from stomach collections during AFSC trawl surveys and from stomachs collected by fishery observers during commercial fishing operations during 1982 to 1999 (see Yang, 2003 for stomach content analysis methods). The degree of taxonomic resolution varied depending on prey type. Most fish prey were identified to species with the exception of myctophids, which were identified only to family (Myctophidae). Invertebrate prey species were rarely identified to species. Euphausiids and copepods were identified to order (Euphausiacea and Calanoida, respectively). Data for this analysis were pooled into two-degree longitude areas, from 164°W to 170°E. Sample sizes per species for each two-degree block ranged from 11 to 3588. Diet composition (percent by weight) by two-degree area was calculated for walleye pollock, Pacific cod, Atka mackerel, and Pacific ocean perch. Percent composition of major prey items (> approx. 80%) was examined in detail, the remaining ≈ 20% was summarized as "other species".

Growth

Length and age data from the 2000 AFSC bottom trawl survey were used to examine geographic patterns in growth of northern rockfish (*Sebastes polyspinis*) and Pacific ocean perch, the two Aleutian rockfish species for which age data have been collected. Data were stratified by North Pacific Fishery Management Council (NPFMC) regulatory areas (Fig. 1), defined as "eastern" Aleutians (541), "central" Aleutians (542) and "western" Aleutians (543). Note that area 541 is actually west of Samalga Pass and thus corresponds to what has been termed "central" Aleutians by other authors in this volume and in other sections of this paper. Area 610 is defined as "western Gulf of Alaska (GOA)", but because this area lies east of Samalga Pass it is analogous to what has been called "eastern" Aleutians in other sections of this paper.

Growth curves for northern rockfish and Pacific ocean perch were based on estimated population numbers at length from the 1997 and 2000 survey and the length-at-age data from the samples of aged fish. These data provide a basis for an analysis of differences in length at age between areas. The otoliths collected in each year and subarea were obtained with length-stratified sampling, and unbiased estimates of mean length at age were produced by multiplying the estimated numbers at length by the age-length key. The use of age-length keys requires length composition estimates from the same year as the otolith collection, and thus separate analyses were conducted for the 1997 and 2000 data. The results presented here were produced from the 2000 data; the 1997 data produced nearly identical patterns. Mean length at age was calculated, accounting for the length-stratified sampling in the survey as described above. The standard deviation of mean length at age was obtained from the delta method (Dorn, 1992). Sample sizes for aged northern rockfish were: 199 fish in area 541, 275 in area 542, and 228 in area 543, whereas samples sizes for Pacific ocean perch in these area were 428, 319, and 357, respectively. The von Bertalanffy model was used to estimate growth curves:

$$L_t = L_\infty (1 - e^{(-k*(t-t_0))}) \qquad [3]$$

where L_t is length at age t (in years), L_∞ is the mean asymptotic length, t_0 is the theoretical age at which a fish would have been zero length, and k is a constant. Growth curves for each species were estimated from data in areas 541, 542, 543 and compared to model parameters (L_∞, k and t_0) estimated by Malecha and Heifetz (2000) from data collected in area 610.

RESULTS

Species occurrence

Approximately 245 fish species were identified in surveys in the Aleutian Islands. Of these, only 63 met the criteria for inclusion in the analysis of species occurrence patterns relative to Aleutian passes. Of these 63 species considered, there was a large percent decline (28%) in the number of demersal fish species between Unimak/Samalga and Amukta Passes (Table 1). The number of these 63 species occurring in the region between Samalga and Amchitka Passes remained relatively constant, declining by only 4%. There was another decline in number of species further west, beyond Buldir Island (20%). Patterns in the distribution of species with respect to their presumed geographic province were also evident. Approximately one-third of the species with Oregonian affinities were not found further west than Unimak Pass, another third were not found further west than Samalga Pass (Table 1). In contrast to the Oregonian species, approximately 70% of Kurile species are found across the entire Aleutian Islands chain.

Demersal community structure

The demersal community cluster analysis yielded five species assemblages (Table 2). Two of the species assemblages were dominated by Atka mackerel and tended to be stratified by depth: the <100 m "Shallow Atka cluster" and the 100-200 m "Deep Atka cluster" (Table 2 and Fig. 3). The primary difference in the species composition of these two clusters was the abundance of Pacific ocean perch and walleye pollock, which were proportionally more abundant in the deep Atka cluster than in the shallow Atka cluster. The "Pacific ocean perch cluster" and "deep cluster" likewise showed unique depth distributions (Table 2 and

Fig. 3). The Pacific ocean perch cluster was made up of strata at depths ranging from 200-300 m and was dominated by Pacific ocean perch and walleye pollock. The deep cluster was made up of strata at depths ranging from 300-500 m and was dominated by giant grenadier (*Albatrossia pectoralis*), Kamchatka flounder (*Atheresthes evermanni*) and shortraker rockfish (*Sebastes borealis*) (Table 2). The "northeast shallow shelf cluster" was the only assemblage that showed a longitudinal pattern. The strata containing this species assemblage were found exclusively north of the Aleutian chain and east of Adak Strait (Fig. 3). This assemblage was also the most diverse – no single species dominated the cluster; instead arrowtooth flounder, Pacific cod, Pacific halibut (*Hippoglossus stenolepis*), rock soles (*Lepidopsetta* spp.), and walleye pollock each made up 12 to 22% of the average cluster biomass (Table 2).

Rockfish community structure

The rockfish cluster analysis yielded six assemblages: northern rockfish – Atka mackerel, Pacific cod, northern rockfish – small Pacific ocean perch, rougheye rockfish (*Sebastes aleutianus*) – shortraker rockfish, large Pacific ocean perch and miscellaneous rockfish – Pacific cod (Table 3). Similar to the demersal community cluster analysis, this analysis identified a Pacific ocean perch cluster and a cluster dominated by northern rockfish and Atka mackerel. Rockfish species that clustered together had unique habitat preferences based on depth or location along the Aleutian Islands chain. The rougheye – shortraker rockfish, large Pacific ocean perch and miscellaneous rockfish – Pacific cod clusters were all found in relatively deep waters of the outer shelf and upper slope (101-500 m). Within these deep waters, each species cluster showed a distinct depth preference. The rougheye –

shortraker rockfish cluster was found in the deepest waters, followed by large Pacific ocean perch and miscellaneous rockfish – Pacific cod (Fig. 4). The median depth (and the 25th to 75th percentile) of the miscellaneous rockfish – Pacific cod cluster was greater than the median (and 25th to 75th percentile) of the northern rockfish – Atka mackerel, Pacific cod and northern rockfish – small Pacific ocean perch clusters. These latter three clusters were all found at shallower depths on the middle shelf (51-150 m) and there was no evidence of unique depth preference among the three groups. However, differences in longitudinal distribution were evident. The northern – small Pacific ocean perch cluster occurred predominantly east of Amchitka pass and the northern – Atka mackerel cluster occurred predominantly to the west of the pass (Fig. 5).

Distribution and abundance

The number of survey hauls used to calculate CPUE in each ¼ degree longitude interval is summarized in Figure 6a. Atka mackerel and Pacific ocean perch were binned into 0, <100 and >100 kg ha^{-1} categories. Walleye pollock CPUE was binned into 0, <50 and >50 kg ha^{-1} categories; and Pacific cod CPUE into 0, <25 and >25 kg ha^{-1} categories. Atka mackerel catches greater than 100 kg ha^{-1} occurred almost exclusively in the western and central Aleutians, west of Samalga Pass (Fig. 6b). High walleye pollock and Pacific cod catches (greater than 50 and 25 kg ha^{-1}, respectively) were observed east and west of Samalga Pass (Fig. 6c and d). High catches of walleye pollock (>50 kg ha^{-1}) were found in the 50 – 300 m depth strata east of Samalga Pass, and in the 100 – 400 m depth strata west of Samalga Pass (Fig. 6c). Walleye pollock catches were almost exclusively <50 kg ha^{-1} west of Buldir Island. Atka mackerel and Pacific ocean perch catches greater than 100 kg ha^{-1} occurred east and west of Buldir Island (Fig. 6b and e). Pacific cod catches greater than 25 kg ha^{-1} likewise occurred east and west of Buldir Island.

Differences in the spatial and depth-distributions of fish independent of longitude were also found. Except in the far west, high catches of Atka mackerel (>100 kg ha^{-1}) were always in the two shallowest depth strata (50 – 200 m) (Fig. 6b). In contrast, high Pacific ocean perch catches (>100 kg ha^{-1}) occurred almost exclusively within the 100 – 400 m depth intervals (Fig. 6e).

Atka mackerel and Pacific ocean perch were more patchily distributed than walleye and Pacific cod. Seventy percent and 52% of hauls had zero catches of Atka mackerel and Pacific ocean perch, respectively, whereas 32% and 45% of hauls had zero catches of Pacific cod and walleye pollock. On average, however, Atka mackerel and Pacific ocean perch catches were more than twice as large as those for walleye pollock and Pacific cod. Average CPUE of Atka mackerel and Pacific ocean perch was 116 kg ha^{-1} and 114 kg ha^{-1}, while average CPUE of walleye pollock and Pacific cod was 47.4 kg ha^{-1} and 24.8 kg ha^{-1}. Several localized areas with high Atka mackerel and Pacific ocean perch catches were evident. Large Atka mackerel catches (> 100 kg ha^{-1}) were found at Samalga, Seguam and Tanaga Passes; and at Petrel Bank and Buldir and Tahoma Reefs (Fig. 6b). High Pacific ocean perch catches (>100 kg ha^{-1}) occurred south of Amlia Island (near Seguam Pass), Petrel Bank, Buldir and Tahoma Reefs, and Stalemate Bank (Fig. 6e).

Food habits

The size range of fish sampled for food habits was 14 to 55 cm FL for Atka mackerel, 13 to 124 cm FL for Pacific cod, 6 to 58 cm FL for Pacific ocean perch and 13 to 72 cm FL for walleye pollock. Longitudinal patterns in diet were apparent in the data. Euphausiids made up 50-90% of the diets of Pacific ocean perch, walleye pollock, and Atka mackerel east of Samalga Pass (from 164° W to 168° W) (Figs 7a, b and c). In contrast, euphausiids generally made up less than 50% of the diets of these fishes west of Samalga Pass. Copepods and myctophids dominated the remaining portion of the diets to the west. The declining trend in the proportion of euphausiids in the diets of Pacific ocean perch and Atka mackerel continued from Samalga Pass to the far western Aleutian Islands. The diet composition of Pacific cod likewise showed a shift near Samalga Pass (Fig. 7d). East of 170° W Pacific cod diets were dominated by walleye pollock, whereas west of 170° W Atka mackerel became an increasingly abundant component of the diet (beginning at around 174° W). The remainder of Pacific cod diet west of Samalga Pass was dominated by shrimp, squid and other fishes, different from the region east of the pass where these taxa comprised a small component of the diet.

In addition to the shift in diet composition at Samalga Pass, there appeared to be changes in diet further west. The proportion of myctophids in the diets of Pacific ocean perch increased dramatically west of 176° E, near Buldir Island (Fig. 7a). In contrast, the proportion of myctophids in the diet of walleye pollock decreased towards the west (Fig. 7b). The remainder of walleye pollock diet to the west was composed of copepods, squid and other invertebrates.

Growth

Longitudinal trends in fish growth were observed. For northern rockfish, collected in 2000, for a given age (above approx. age 3) fish length increased from west to east among the three Aleutian Islands NPFMC regulatory areas (541, 542, 543) (Fig. 8a). Data collected in 1997 (not shown) produced nearly identical patterns. In contrast to the results for northern rockfish, the geographic changes in the estimated growth curves were less dramatic for Pacific ocean perch (Fig. 8b).

DISCUSSION

As revealed in several other studies published in this volume, Samalga Pass is a major biophysical transition zone in the Aleutian Islands region. Surface waters west of Samalga Pass are oceanic (cold, salty and nutrient-rich), whereas surface waters east of the pass are coastal (warm, fresh and nutrient poor; Ladd *et al.*, 2005a; Mordy *et al.*, 2005). This transition is the result of Aleutian-wide current patterns (Ladd *et al.*, 2005a) and increased advection from the Bering Sea combined with greater depth of mixing in the passes west of Samalga (Ladd *et al.*, 2005a). Despite the fact that nutrient levels are higher west of Samalga Pass, primary production is lower perhaps due to mixing of phytoplankton below the euphotic zone and iron-limitation (Mordy *et al.*, 2005). The species composition of the zooplankton community reflects the water mass differences east and west of Samalga Pass. Neritic copepod and euphausiid species are most abundant to the east and oceanic copepod and euphausiid species are most abundant to the west (Coyle, 2005; Coyle and Pinchuk, 2005).

Many characteristics of the demersal fish community likewise change at Samalga Pass. There is a strong decline in the number of fish species from east to west of the pass. This decline may be a reflection of the relatively poor primary production in the central and western Aleutian Islands region (Mordy *et al.*, 2005). In addition, the passes west of Samalga are relatively deep and lack zones of upward advection and surface convergence which are important for foraging seabirds (Ladd *et al.*, 2005b) and possibly other top level predators such as demersal fishes.

The distribution of species changes at Samalga Pass. Species with Oregonian affinities are more numerous east of the pass, whereas species with Kurile affinities are distributed throughout the Aleutian Islands region. Although the species included in these analyses have a variety of life histories, nearly all have pelagic larvae. Thus, currents are expected to influence their dispersal patterns and range boundaries (Palumbi, 1994; Briggs, 1995; Gaylord and Gaines, 2000). Samalga Pass is the westernmost extent of the west-flowing Alaska Coastal Current, which may explain why species with Oregonian affinities are found primarily east of the pass. The passes west of Samalga are also relatively deep and increasingly wide, such that they may serve as additional barriers to westerly dispersal for some species. That Kurile species are found throughout the Aleutian Islands region suggests that species that cross the distance between the Commander Islands to the far west and Attu Island (the westernmost island in the Aleutian region) are generally able to disperse widely, even across deep and broad passes such as the Kamchatka Strait, Near Strait and Amchitka Pass. Examination of genetic differentiation among Aleutian Island endemic populations and among species could also lend insight into dispersal patterns. In addition, newly described fish species (Orr and Busby, 2001; Stevenson *et al*., 2004, Orr, 2004) that appear to be endemic to the east-central Aleutian Islands suggest that vicariant geological events have also affected the speciation and distribution of species in the area.

In addition to changes in species richness and geographic affinities, we observed changes in the distribution and abundance of fish populations at Samalga Pass. For instance, Atka mackerel are more abundant west of Samalga Pass. This trend is opposite to that of primary productivity (Mordy *et al.*, 2005), but instead could be a reflection of the relative increase of oceanic zooplankton west of Samalga. Euphausiids and calanoid copepods are the most frequent food item of Atka mackerel in the Aleutian Islands region (Yang, 2003). However, Yang (2003) did not identify zooplankton to species, so it is not known whether Atka mackerel prefer oceanic to neritic species of euphausiids and copepods. Further detailed study of the zooplankton composition of Atka mackerel diets is necessary to test the hypothesis that the increase in Atka mackerel abundance west of Samalga Pass is due to the increase in oceanic species in the zooplankton community.

Fisheries scientists have long recognized that Gulf of Alaska and Aleutian Islands Atka mackerel show significant differences in population size, distribution, recruitment patterns, and resilience to fishing (Lowe *et al*., 2003). Despite genetic similarities, there do appear to be different environmental factors affecting these two populations giving rise to phenotypic differences in morphological traits such as weight-at-age (Kimura and Ronholt, 1988) and meristic traits such as number of fin rays, vertebrae and gill rakers (Levada, 1979). However, the precise boundary of these two populations is not known, nor are mechanisms for differentiation proposed. Our work shows that the transition between the Gulf of Alaska and Aleutian Island populations likely occurs at or near Samalga Pass and indicates that future work on the mechanisms of population differentiation (genetics, growth, fecundity, mortality, etc.) should focus on the Samalga Pass area.

Finally, we found that the diet of demersal fishes changes at Samalga Pass. Similar to changes observed in northern fulmar diets (Jahncke *et al.*, 2005), euphausiids are more abundant in the diets of walleye pollock, Atka mackerel and Pacific ocean perch east of Samalga Pass. West of this pass, copepods and myctophids make up a relatively large proportion of the diets of these fishes. Although both copepods and euphausiids are found throughout the Aleutian Islands region, a detailed comparison of the distribution of zooplankton across a shallow eastern pass (Amukta) and a deep central pass (Seguam) showed that euphausiids are relatively more abundant at Akutan Pass and are concentrated near the bottom (Coyle, 2005). Euphausiids are less abundant, less densely aggregated and shallower at Seguam Pass. We hypothesize that the dominance of euphausiids in the diets of demersal fishes east of Samalga Pass is due to the effects of pass geometry on the distribution of euphausiids with the result that euphausiids are more available to demersal fishes in the shallow passes to the east. Further study of the distribution of euphausiids among Aleutian passes and of the distribution of foraging demersal fishes is needed to confirm this hypothesis.

In addition to the significant transition zone at Samalga Pass, there may be additional transition zones in the western Aleutians that have not yet been identified oceanographically. Buldir Island is an area where several demersal fish characteristics change. At the community level, the number of fish species declines from east to west of Buldir Island and at the population level, walleye pollock survey catches are lower west of Buldir Island. The passes west of Buldir are some of the deepest in the Aleutian Islands region. They provide most of the transport from the North Pacific to the Bering Sea but likely contribute few nutrients to the euphotic zone (Stabeno *et al.*, 2005). This decline in productive potential may contribute to the decline in species richness in general and walleye pollock abundance in particular.

Another potential transition zone occurs at Amchitka Pass. Two rockfish community clusters show distinct geographic distributions, with the northern rockfish – Atka mackerel cluster occurring almost exclusively west of Amchitka Pass and the northern rockfish – Pacific ocean perch cluster occurring east of the pass. Amchitka Pass appears to be an area where currents diverge, perhaps resulting in different water mass properties from east to west. Modeling results suggest that waters crossing Amchitka Pass from the North

Pacific into the Bering Sea turn east, forming the westernmost extent of the Aleutian North Slope Current. The model also shows that a portion of the Bering Sea current flow from the west towards Amchitka Pass is diverted north and west at Bower's Ridge, located immediately west of the pass (Maslowski, personal communication). Further physical and biological oceanographic study of current patterns, water column properties and primary production is needed to determine if transition zones exist west of the transition zone already documented at Samalga Pass (Ladd *et al.*, 2005a).

In addition to step-changes at Samalga Pass, Buldir Island and Amchitka Pass, there are longitudinal trends in demersal fish characteristics that indicate continuous physical and biological variation along the length of the Aleutian Islands chain. The most striking is the longitudinal trends in northern rockfish growth. Size at age declines from east to west. Growth parameters from the westernmost Gulf of Alaska management area (Malecha and Heifetz, 2000) show that northern rockfish farther east are comparable with the eastern Aleutians (Table 4). Similarly, estimated growth curves for Atka mackerel show that fish are largest in the western Gulf of Alaska and smallest in the western Aleutians (Lowe et al., 1998); Fig. 9). Our current understanding of northern rockfish and Atka mackerel genetics indicates that mechanisms at the evolutionary scale are not involved. An analysis of 37 protein-coding gene loci provide no support for Atka mackerel genetic stock structure within the Aleutian Islands region (Lowe *et al.*, 1998), although further genetic studies employing microsatellite DNA are currently being pursued at AFSC. Geographic growth differences that exist despite the lack of genetic differentiation may be a result of a single stock that mixes during the pelagic larval and juvenile stages but then aggregates during the demersal adult stage (Lowe *et al.*, 1998). The combination of the westward-flowing Alaska

Stream, the eastward flowing Aleutian North Slope Current and northward flow through the passes (Ladd *et al.*, 2005a) would likely facilitate this mixing of pelagic life history stages. For this hypothesis to be justified, growth patterns would need to be established in the adult stage after fish have settled in a particular region. A preliminary study of northern rockfish genetics similarly showed no evidence of population structure among samples collected at Kodiak Island (Gulf of Alaska), Unimak Pass (eastern Aleutians) and Stalemate Bank (western Aleutians) (A. Gharrett, University of Alaska Fairbanks, USA, pers. comm.). However, the sample sizes were small and much larger sample sizes will be required to identify possible subtle changes in genetic structure.

Atka mackerel and northern rockfish growth differences may not be the result of genetically isolated stocks but may instead represent phenotypic expression of environmental differences among areas within the Aleutian Islands region. The environmental factors that determine growth of these fishes are not known, but the decline in growth rate from east to west could be related to the decline in primary productivity towards the west (Mordy *et al.*, 2005). Understanding growth patterns is important because, for practical fisheries management, population parameters such as mortality, spawning behavior and growth are particularly useful for recognition of stocks (Casselman *et al.*, 1981; Ihssen *et al.*, 1981). The growth differences among regions within the Aleutian Islands suggests that in addition to large-scale phenotypic differentiation between Aleutian Islands and Gulf of Alaska fishes (Lowe *et al.*, 2003), there may also be important differences occurring at a smaller scale within the Aleutians.

In contrast to the results for northern rockfish and Atka mackerel, there is little geographic pattern in the estimated growth curves for Pacific ocean perch. Information on the early life history of Atka mackerel, northern rockfish and Pacific ocean perch is sparse, except that each has pelagic larval and early juvenile stages of unknown duration. The difference in growth patterns of the three species would be consistent with a longer pelagic stage for Pacific ocean perch, such that growth patterns are established before fish are distributed into separate spawning locations. In contrast, a relatively short pelagic stage for Atka mackerel and northern rockfish could result in less mixing of sub-adults and stronger geographic differentiation of growth patterns. Further information on the early life history of these three fish species is needed to evaluate this hypothesis.

In addition to biophysical transition zones and longitudinal trends, analysis of demersal fish distributions shows that some species are more patchily distributed than others and that high catches of these patchily distributed species occur in areas expected to be biological "hot spots" due to increased productivity and prey availability. "Hot spots" (areas of hydrographically-generated prey aggregations) are important for predators in many other systems (Olson and Backus, 1985; Fiedler and Bernard, 1987; Schneider, 1990; Lang *et al.*, 2000; Brodeur, 2001). In the Aleutian Islands, Atka mackerel and Pacific ocean perch occur at exceptionally high densities at passes such as Samalga, Seguam and Tanaga. These passes are of intermediate depth (120 to 200 m) and are efficient at mixing nutrients upwards because their sills are deeper than the nutricline but shallow enough so that strong tidal currents can mix the water column vertically and introduce nutrients into the euphotic zone (Stabeno *et al.*, 2005). The interaction of currents with bathymetry also creates upward advection and surface convergence that aggregate prey and are expected to facilitate foraging by seabirds and other predators (Ladd *et al.*, 2005b). Atka mackerel and Pacific ocean perch are also abundant at banks and reefs such as Petrel Bank, Buldir Reef and Tahoma Reef. The shallowing of the water in these areas similarly might be expected to result in mixing of nutrients into the euphotic zone, increased production and prey aggregation. Aleutian Island passes are important foraging areas for other predators, such as cetaceans and Steller sea lions (Sinclair *et al.*, in review).

Another important feature of the Aleutian ecosystem is changes in demersal fish habitat with depth. We find that depth-related patterns are as common as longitudinal patterns in fish distribution. For instance, cluster analyses of the demersal community in general, and the rockfish community in particular show distinct depth preferences for groups of species. Atka mackerel and northern rockfish are distributed at relatively shallow depths on the shelf whereas pollock and Pacific ocean perch distribution extends to the outer shelf. Giant grenadier, Kamchatka flounder, shortraker rockfish and associated species are distributed over the outer shelf and slope. Mueter and Norcross (2002) and Brodeur (2001) report similar depth ranges for rougheye rockfish, shortraker rockfish, Pacific ocean perch and giant grenadier in the Gulf of Alaska and Bering Sea.

Fish species that cluster together have similar habitat preferences (Auster *et al.*, 2001; Williams and Ralston, 2002), however very little is known about habitat requirements of Aleutian Islands fishes. Studies of *Sebastes* rockfishes in other systems indicate a dependence on hard bottom substrates with high vertical relief (O'Connell & Carlile, 1993; Pearcy *et al.*, 1989; Krieger and Ito, 1999), with the possible exception of Pacific ocean perch, which have been found to inhabit flat, pebble substrate in Southeast Alaska (Krieger, 1992). Consistent with these studies, the shallower waters in the Aleutian Islands region where northern rockfish and Atka mackerel are found are thought to be characterized by especially rocky bottom.

These patterns in demersal fish ecology are new findings for the Aleutian Islands region. We find step-changes at Samalga Pass and sites farther west, patchily distributed species at biological “hot spots”, longitudinal trends and depth-related variation. In interpreting these patterns, we suggest linkages between demersal fish ecology and the biophysical processes described by other authors in this volume. Because the mechanisms resulting in these linkages are largely unknown, we recommend inter-disciplinary research combining observations of the physical and biological oceanographic properties of the water column, bottom habitat, and demersal fish ecology (species occurrence, community structure, distribution and abundance, food habits and growth).

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Table 1 . Demersal fishes with partial distributions in the Aleutian Islands, classified by zoogeographic provinces (Allen and Smith, 1988).
Passes listed are the easternmost boundaries of areas in which species occurrence was tabulated. "X" indicates records of this species

Taxon	Common name	Unimak	Samalga	Amukta	Tanaga	Amchitka	Buldir
Arctic-Kurile Province							
Anisarchus medius	Stout eelblenny	X					
Lumpenus fabricii	Slender eelblenny	X					
Anarhichas orientalis	Bering wolffish	X					
Ocella dodecahedron	Bering poacher	X					
Platichthys quadrituberculatus	Alaska plaice	X	X				
Eleginus gracilis	Saffron cod	X	X				
Aspidophoroides monopterygius	Alligatorfish	X	X	X	X	X	
Leptoclinus maculatus	Daubed shanny	X	X	X	X	X	
Lumpenus sagitta	Snake prickleback	X	X	X	X	X	
Kurile Province							
Lumpenella longirostris	Longsnout prickleback	X					
Icelus canaliculatus	Blacknose sculpin*	X	X	X	X	X	X
Bathyraja lindbergi	Commander skate	X	X	X	X	X	X
Bathyraja minispinosa	Smallthorn skate	X	X	X	X	X	X
Bathyraja maculata	White-blotched skate	X	X	X	X	X	X
Sebastolobus macrochir	Broadbanded thornyhead	X	X	X	X	X	X
Careproctus ostentum	Microdisk snailfish	X	X	X	X	X	X
Careproctus simus	Proboscis snailfish	X	X	X	X	X	X
Elassodiscus tremebundus	Dimdisk snailfish	X	X	X	X	X	X
Careproctus zachirus	Blacktip snailfish		X	X	X	X	X
Hemilepidotus zapus	Longfin Irish lord		X	X	X	X	X
Thyriscus anoplus	Sponge sculpin		X	X	X	X	X
Allocareproctus jordani	Jordan's allocareproct		X	X	X	X	X
Bathyraja violacea	Okhotsk skate		X	X	X	X	X
Bathyraja taranetzi	Mud skate		X	X	X	X	X
Sigmistes smithi	Arched sculpin			X	X	X	X
Icelus uncinalis	Uncinate sculpin					X	X
Percis japonica	Dragon poacher						X
Oregonian Province							
Synchirus gilli	Manacled sculpin	X					
Icelus spatula	Spatulate sculpin	X					
Artedius lateralis	Smoothhead sculpin	X					
Leptocottus armatus	Pacific staghorn sculpin	X					
Bathyagonus alascanus	Gray starsnout	X					
Hypomesus pretiosus	Surf smelt	X					
Raja rhina	Longnose skate	X					
Sebastolobus altivelis	Longspine thornyhead	X					
Sebastes brevispinis	Silvergray rockfish	X					
Lycodes brevipes	Shortfin eelpout	X					
Anarrhichthys ocellatus	Wolf-eel	X					
Eopsetta jordani	Petrale sole	X					
Artedius fenestralis	Padded sculpin	X	X				
Artedius harringtoni	Scalyhead sculpin	X	X				
Sebastes flavidus	Yellowtail rockfish	X	X				
Sebastes ruberrimus	Yelloweye rockfish	X	X				
Cryptacanthodes giganteus	Giant wrymouth	X	X				
Cryptacanthodes aleutensis	Dwarf wrymouth	X	X				
Raja binoculata	Big skate	X	X				
Bathyraja interrupta	Sandpaper skate	X	X				
Microgadus proximus	Pacific tomcod	X	X				
Bathyagonus infraspinatus	Spinycheek starsnout	X	X				
Psettichthys melanostictus	Pacific sand sole	X	X				
Lepidopsetta bilineata	Rock sole	X	X				
Isopsetta isolepis	Butter sole	X	X				
Psychrolutes paradoxus	Tadpole sculpin	X	X	X	X		
Sebastes crameri	Darkblotched rockfish	X	X	X	X		
Thaleichthys pacificus	Eulachon	X	X	X	X	X	
Sebastes babcocki	Redbanded rockfish	X	X	X	X	X	
Sebastes melanops	Black rockfish	X	X	X	X	X	
Sebastes variegatus	Harlequin rockfish	X	X	X	X	X	
Sebastes proriger	Redstripe rockfish	X	X	X	X	X	
Poroclinus rothrocki	Whitebarred prickleback	X	X	X	X	X	
Ronquilus jordani	Northern ronquil	X	X	X	X	X	
Triglops macellus	Roughspine sculpin	X	X	X	X	X	X
Anoplagonus inermis	Smooth alligatorfish	X	X	X	X	X	X
Total number of species		54	43	29	29	28	19

Table 2. Mean proportion of the average cluster biomass for each species. Clusters are: shallow Atka cluster (SAC), deep Atka cluster (DAC), Pacific ocean perch cluster (POP), deep cluster (DEEP) and northeast shallow shelf cluster (NESSC). All proportions greater than 0.10 are shaded in gray.

Common Name	Species Name	SAC	DAC	POP	DEEP	NESSC
Alaska skate	*Bathyraja parmifera*	0.006	0.004	0.002	0.001	0.007
Aleutian skate	*Bathyraja aleutica*	0.001	0.002	0.003	0.002	0.003
arrowtooth flounder	*Atheresthes stomias*	0.003	0.020	0.044	0.040	0.166
Atka mackerel	*Pleurogrammus monopterygius*	0.616	0.418	0.031	0.000	0.003
Bering skate	*Bathyraja interrupta*	0.000	0.000	0.000	0.001	0.000
big skate	*Raja binoculata*	0.000	0.000	0.000	0.000	0.003
butter sole	*Isopsetta isolepis*	0.000	0.000	0.000	0.000	0.000
Dover sole	*Microstomus pacificus*	0.000	0.000	0.000	0.001	0.000
dusky rockfishes unid.		0.001	0.000	0.000	0.000	0.001
English sole	*Parophrys vetulus*	0.000	0.000	0.000	0.000	0.000
flathead sole	*Hippoglossoides elassodon*	0.001	0.006	0.001	0.001	0.046
giant grenadier	*Albatrossia pectoralis*	0.000	0.000	0.000	0.411	0.000
Greenland halibut	*Reinhardtius hippoglossoides*	0.000	0.000	0.001	0.061	0.000
grenadier unident.	*Macrouridae*	0.000	0.000	0.000	0.000	0.000
harlequin rockfish	*Sebastes variegatus*	0.000	0.000	0.000	0.000	0.000
Kamchatka flounder	*Atheresthes evermanni*	0.000	0.001	0.007	0.113	0.007
longnose skate	*Raja rhina*	0.000	0.000	0.000	0.000	0.000
magistrate armhook squid	*Berryteuthis magister*	0.000	0.001	0.008	0.005	0.001
mud skate	*Bathyraja taranetzi*	0.000	0.000	0.000	0.003	0.000
northern rockfish	*Sebastes polyspinis*	0.149	0.104	0.002	0.000	0.004
octopus unident.	*Octopodidae*	0.000	0.001	0.001	0.000	0.004

Pacific cod	*Gadus macrocephalus*	0.100	0.074	0.041	0.005	0.125
Pacific grenadier	*Coryphaenoides acrolepis*	0.000	0.000	0.000	0.000	0.000
Pacific halibut	*Hippoglossus stenolepis*	0.030	0.024	0.010	0.012	0.130
Pacific ocean perch	*Sebastes alutus*	0.008	0.188	0.678	0.040	0.069
popeye grenadier	*Coryphaenoides cinereus*	0.000	0.000	0.000	0.000	0.000
prowfish	*Zaprora silenus*	0.002	0.005	0.001	0.000	0.000
redbanded rockfish	*Sebastes babcocki*	0.000	0.000	0.000	0.000	0.000
rex sole	*Glyptocephalus zachirus*	0.000	0.001	0.003	0.007	0.011
rock sole unident.	*Lepidopsetta sp.*	0.063	0.025	0.006	0.000	0.160
rougheye rockfish	*Sebastes aleutianus*	0.000	0.000	0.006	0.035	0.000
sablefish	*Anoplopoma fimbria*	0.000	0.000	0.002	0.023	0.000
sculpin unident.	*Cottidae*	0.007	0.006	0.005	0.009	0.026
shark unident.		0.000	0.000	0.000	0.004	0.006
sharpchin rockfish	*Sebastes zacentrus*	0.000	0.000	0.000	0.000	0.000
shortraker rockfish	*Sebastes borealis*	0.000	0.000	0.002	0.101	0.000
shortspine thornyhead	*Sebastolobus alascanus*	0.000	0.000	0.002	0.032	0.000
skate unident.	*Rajidae unident.*	0.001	0.002	0.001	0.002	0.005
smelt unident.	*Osmeridae*	0.002	0.000	0.000	0.000	0.001
starry flounder	*Platichthys stellatus*	0.000	0.001	0.000	0.000	0.000
walleye pollock	*Theragra chalcogramma*	0.007	0.108	0.137	0.084	0.219
whiteblotched skate	*Bathyraja maculata*	0.002	0.007	0.003	0.009	0.001
yellowfin sole	*Limanda aspera*	0.000	0.000	0.000	0.000	0.000

Table 3. Species assemblages as identified by hierarchical cluster analysis. Individual species are listed in rows, species assemblages in columns. The numbers in each cell represent the proportion of CPUE comprised of each species. Shaded cells represent species that dominate the composition of each assemblage (>10% of CPUE).

	Northern rockfish – Atka mackerel	Pacific cod	Northern rockfish– Small Pacific ocean perch	Rougheye-Shortraker rockfish	Large Pacific ocean perch	Misc. rockfish – Pacific cod
Large rougheye rockfish	0.01	0.00	0.00	0.20	0.10	0.04
Small rougheye rockfish	0.00	0.00	0.00	0.04	0.02	0.02
Large Pacific ocean perch	0.03	0.01	0.00	0.14	0.47	0.29
Small Pacific ocean perch	0.01	0.01	0.32	0.00	0.03	0.13
Northern rockfish	**0.36**	0.07	0.30	0.01	0.07	0.15
Large shortraker rockfish	0.00	0.00	0.00	0.22	0.01	0.01

Small shortraker rockfish	0.00	0.00	0.00	0.06	0.00	0.00
Shortspine thornyhead	0.01	0.00	0.01	0.17	0.15	0.01
Dusky rockfish	0.06	0.01	0.05	0.00	0.01	0.02
Longspine thorneyhead	0.00	0.00	0.00	0.00	0.00	0.00
Harlequin rockfish	0.00	0.00	0.00	0.00	0.00	0.01
Atka mackerel	0.33	0.20	0.07	0.01	0.08	0.09
Large Pacific cod	0.17	0.51	0.08	0.05	0.04	0.19
Small Pacific cod	0.03	0.18	0.17	0.00	0.00	0.02
Large sablefish	0.00	0.00	0.00	0.09	0.01	0.01
Small sablefish	0.00	0.00	0.00	0.01	0.00	0.00

Table 4. Parameters from the von Bertalanffy growth equation for northern rockfish in the three Aleutian Islands NMFS management areas and the western Gulf of Alaska management area (Malecha and Heifetz, 2000).

Management Area	L_∞ (cm)	k	t_0 (years)
West (543)	33.28	0.18	-0.49
Central (542)	35.48	0.16	-0.52
East (541)	40.48	0.18	0.26
W. Gulf of Alaska (610)	39.16	0.17	-0.64

FIGURE LEGENDS

Figure 1. Aleutian Islands with NPFMC regulatory areas referred to in text.

Figure 2. Geographic locations mentioned in text and zoogeographic provinces of the North Pacific (reproduced from Allen and Smith, 1988)

Figure 3. Cluster analysis of the Aleutian Islands survey data using a dissimilarity matrix and agglomerative cluster analysis. Three-number codes in the cluster tree represent NMFS bottom trawl survey strata.

Figure 4. Depth distributions of six species clusters found in the Aleutian Islands survey data (1991-2000). Horizontal lines in the middle of each box represent the median depth, the boxes encompass the 25^{th} to the 75^{th} percentile, whiskers represent the 5^{th} and 95^{th} percentile and the points are the minimum and maximum values. Sample sizes are (n= number of hauls): northern rockfish – Atka mackerel (n=38), Pacific cod (n=504), northern rockfish – small Pacific ocean perch (POP) (n=59), Rougheye – Shortraker rockfish (n=191), large Pacific ocean perch (POP) (n=114), miscellaneous rockfish – Pacific cod (n=468).

Figure 5. Geographic distribution of two species clusters found in the Aleutian Islands survey data (1991-2000), northern rockfish – small Pacific ocean perch (POP) and northern rockfish – Atka mackerel.

Figure 6. Number of AFSC Aleutian Island survey hauls and catch-per-unit effort (CPUE) of selected demersal fish species aggregated in cells of ¼ degree longitude and 100 meter depth intervals. The top panel of each figure represents data from the Bering Sea side of the island chain, the bottom represents the North Pacific side. The depth intervals are shown on the left and ride of each figure, the longitudinal divisions are shown in the center (with the location of selected passes and islands). Note the different CPUE scale range for each figure. a. Number of survey hauls, b. Atka mackerel CPUE, c. walleye pollock CPUE , d. Pacific cod CPUE, e. Pacific ocean perch CPUE.

Figure 7. Diet composition (percent by weight) of four major demersal fish species in the Aleutian Islands by 2-degree longitudinal blocks. Longitude labels refer to the westernmost longitude of the block. The approximate locations of selected passes and Buldir Island are also shown. Unimak Pass is at 165° W, Samalga Pass is at 169° W, Amchitka Pass is at 180° W and Buldir Island is at 176° E a. Pacific ocean perch, b. walleye pollock, c. Atka mackerel, d. Pacific cod.

Figure 8. Estimated growth curves for a) northern rockfish and b) Pacific ocean perch by NMFS management area based on trawl survey data from 2000. Length is fork length.

Figure 9. Estimated growth curves for Atka mackerel by NMFS management area based on trawl survey data from the Aleutian Islands and Gulf of Alaska during 1993 and 1994, respectively (Lowe *et al.*, 1998). Length is fork length.

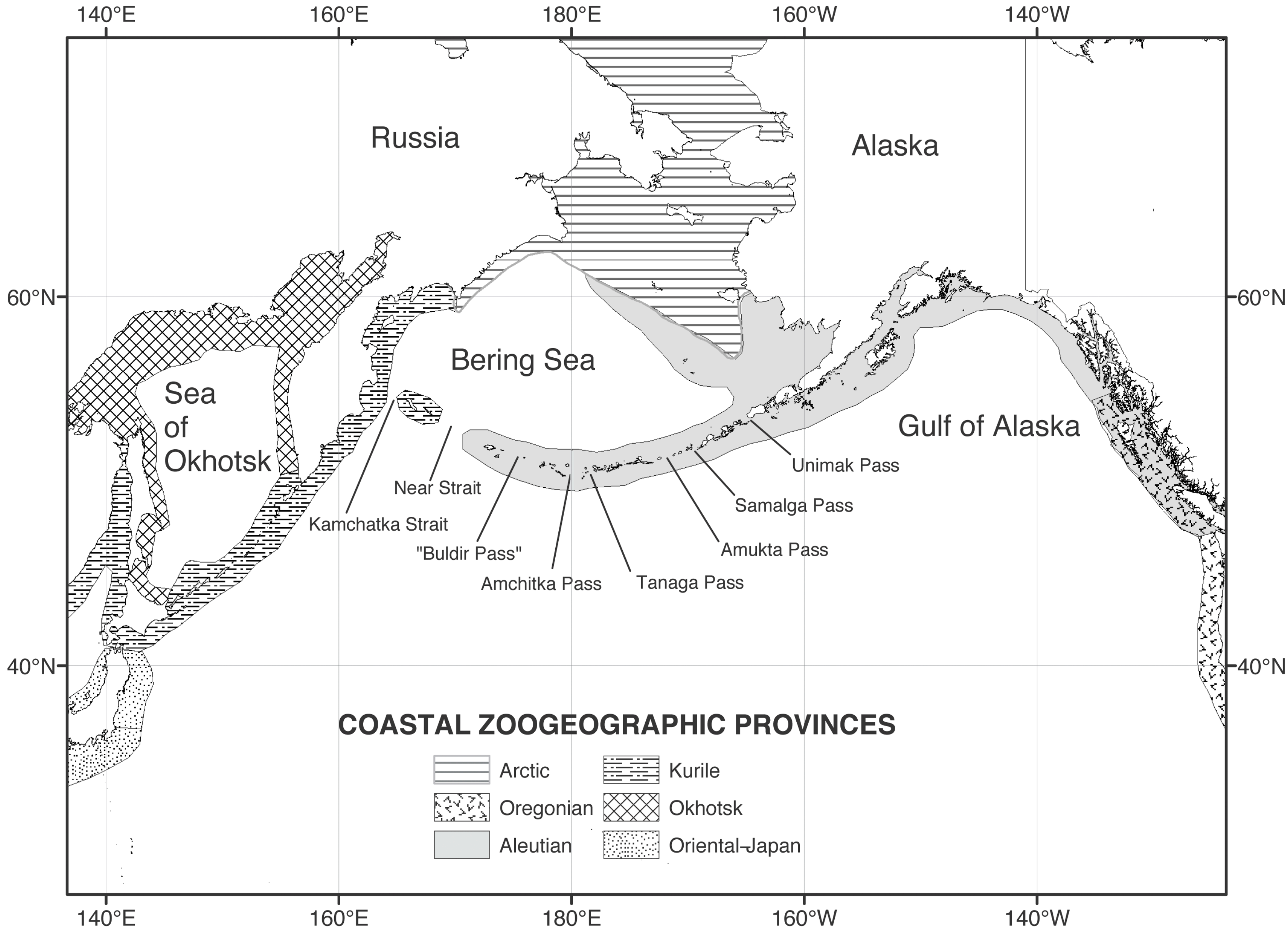
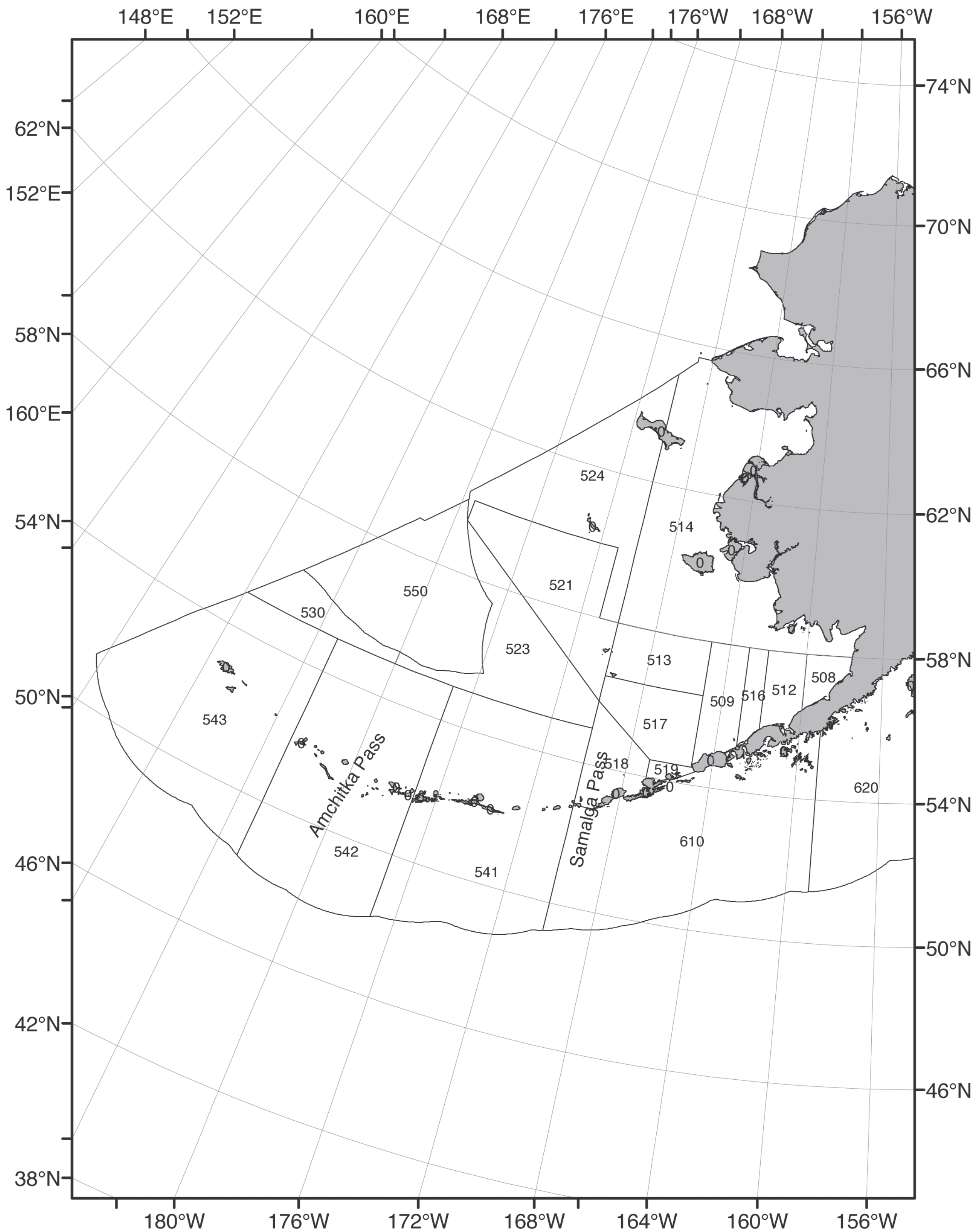
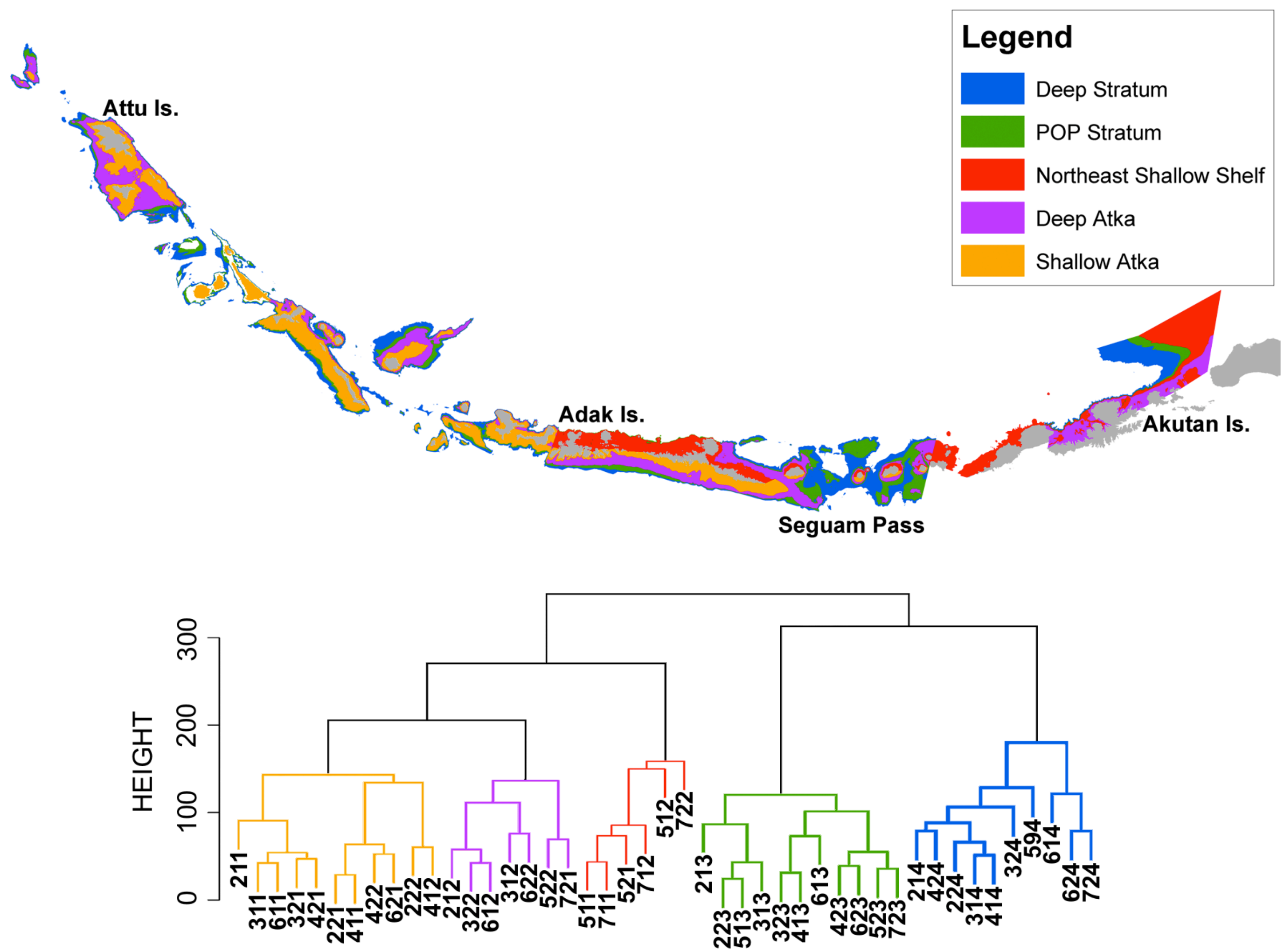

140°E
160°E
180°E
160°W
140°W
60°N
40°N
Russia
Alaska
Bering Sea
Sea
of
Okhotsk
Gulf of Alaska
Near Strait
Kamchatka Strait
"Buldir Pass"
Amchitka Pass
Tanaga Pass
Amukta Pass
Samalga Pass
Unimak Pass
COASTAL ZOOGEOGRAPHIC PROVINCES
Arctic
Oregonian
Aleutian
Kurile
Okhotsk
Oriental-Japan

Fig. 1



148°E
152°E
160°E
168°E
176°E
176°W
168°W
156°W
74°N
70°N
66°N
62°N
58°N
54°N
50°N
46°N
62°N
152°E
58°N
160°E
54°N
50°N
46°N
42°N
38°N
180°W
176°W
172°W
168°W
164°W
160°W
156°W
524
514
521
550
530
523
513
509
516
512
508
517
543
518
519
620
610
542
541
Amchitka Pass
Samalga Pass

Fig. 2



Legend
Deep Stratum
POP Stratum
Northeast Shallow Shelf
Deep Atka
Shallow Atka
Attu Is.
Adak Is.
Seguam Pass
Akutan Is.
HEIGHT
0
100
200
300
211
311
611
321
421
221
411
422
621
222
412
212
322
612
312
622
522
721
511
711
521
712
512
722
213
223
513
313
323
413
613
423
623
523
723
214
424
224
314
414
324
594
614
624
724

Fig. 3

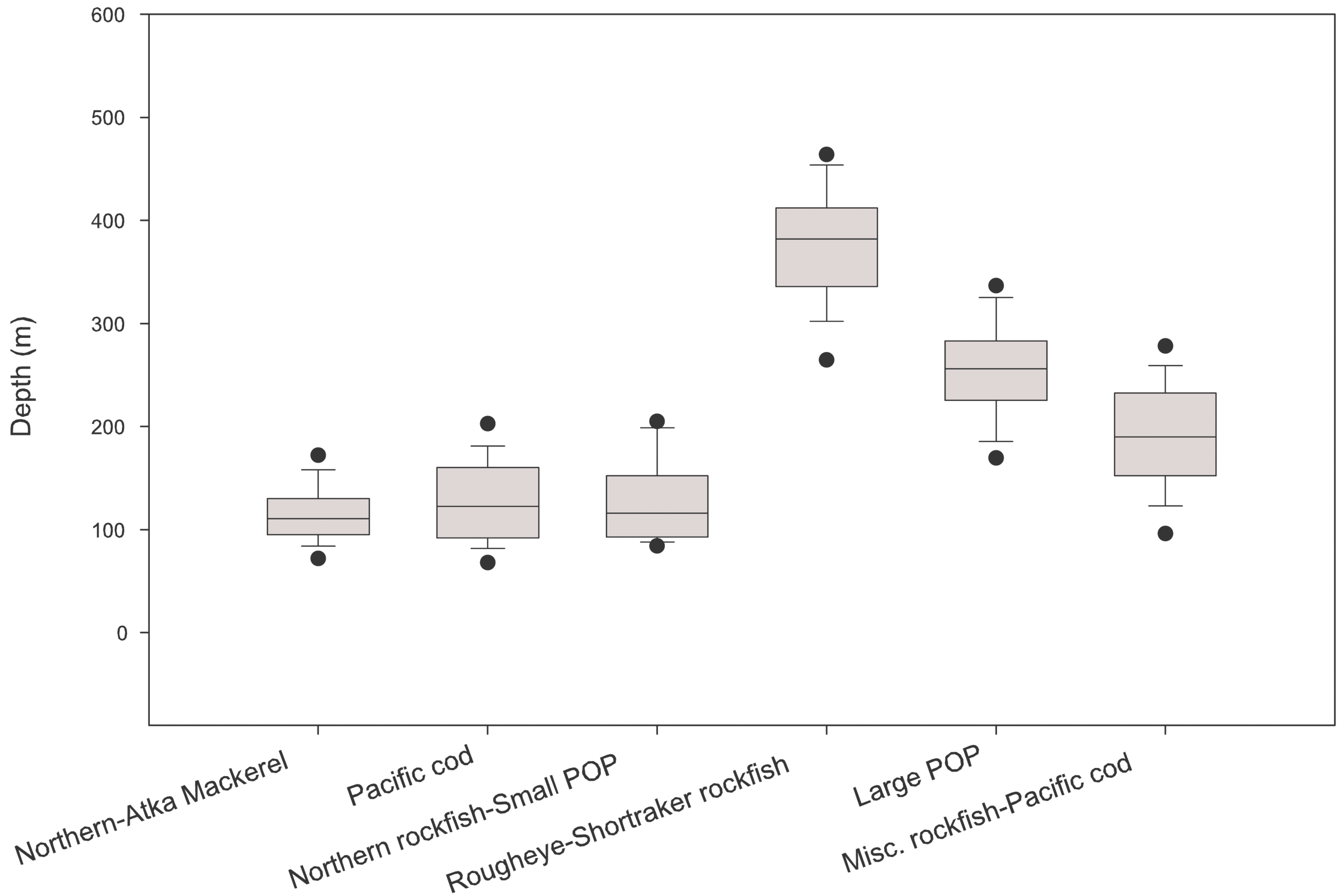
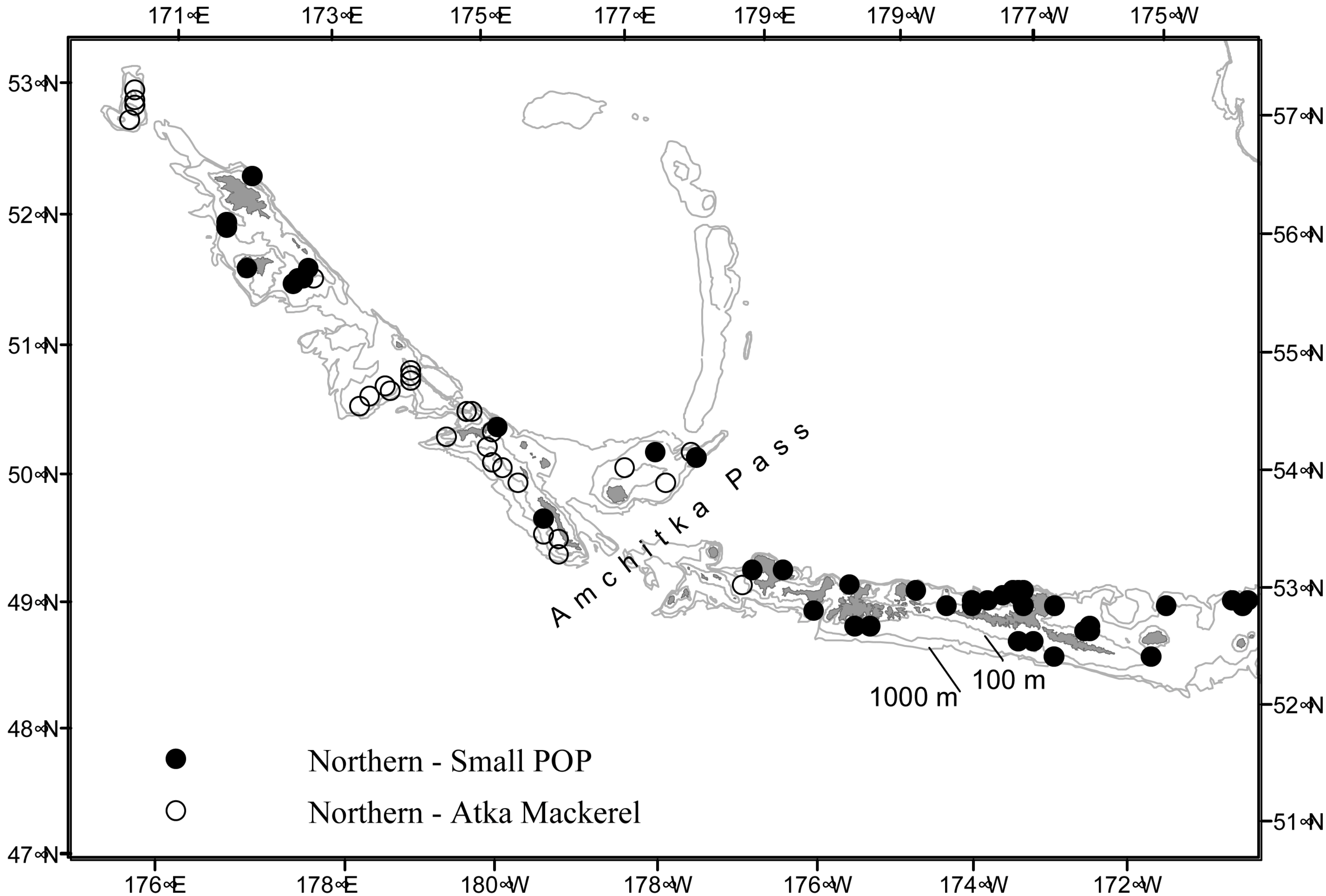

Depth (m)
600
500
400
300
200
100
0
Northern-Atka Mackerel
Pacific cod
Northern rockfish-Small POP
Rougheye-Shortraker rockfish
Large POP
Misc. rockfish-Pacific cod

Fig. 4



171∞E
173∞E
175∞E
177∞E
179∞E
179∞W
177∞W
175∞W
53∞N
52∞N
51∞N
50∞N
49∞N
48∞N
47∞N
57∞N
56∞N
55∞N
54∞N
53∞N
52∞N
51∞N
176∞E
178∞E
180∞W
178∞W
176∞W
174∞W
172∞W
Amchitka Pass
100 m
1000 m
Northern - Small POP
Northern - Atka Mackerel

Fig. 5

a. **Number of Survey Hauls**

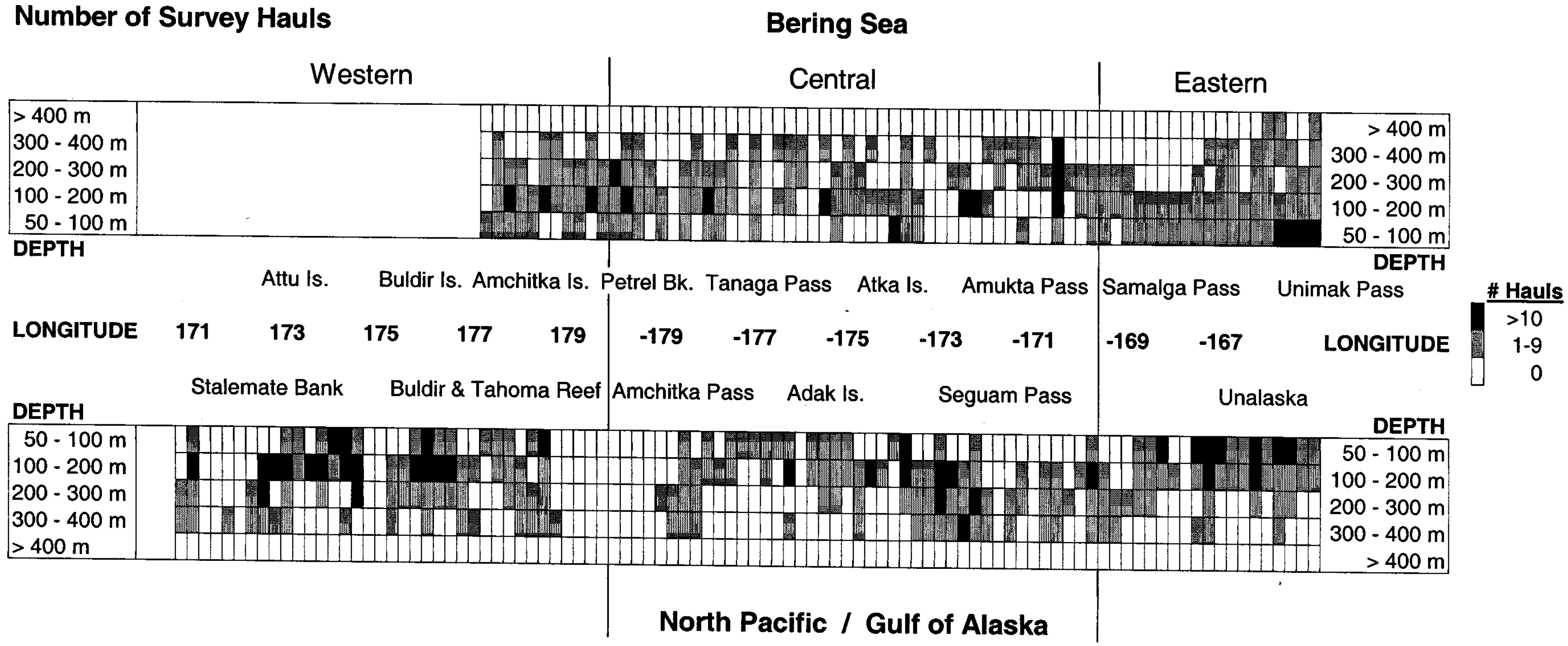


Fig. 6a

b. **Atka Mackerel**

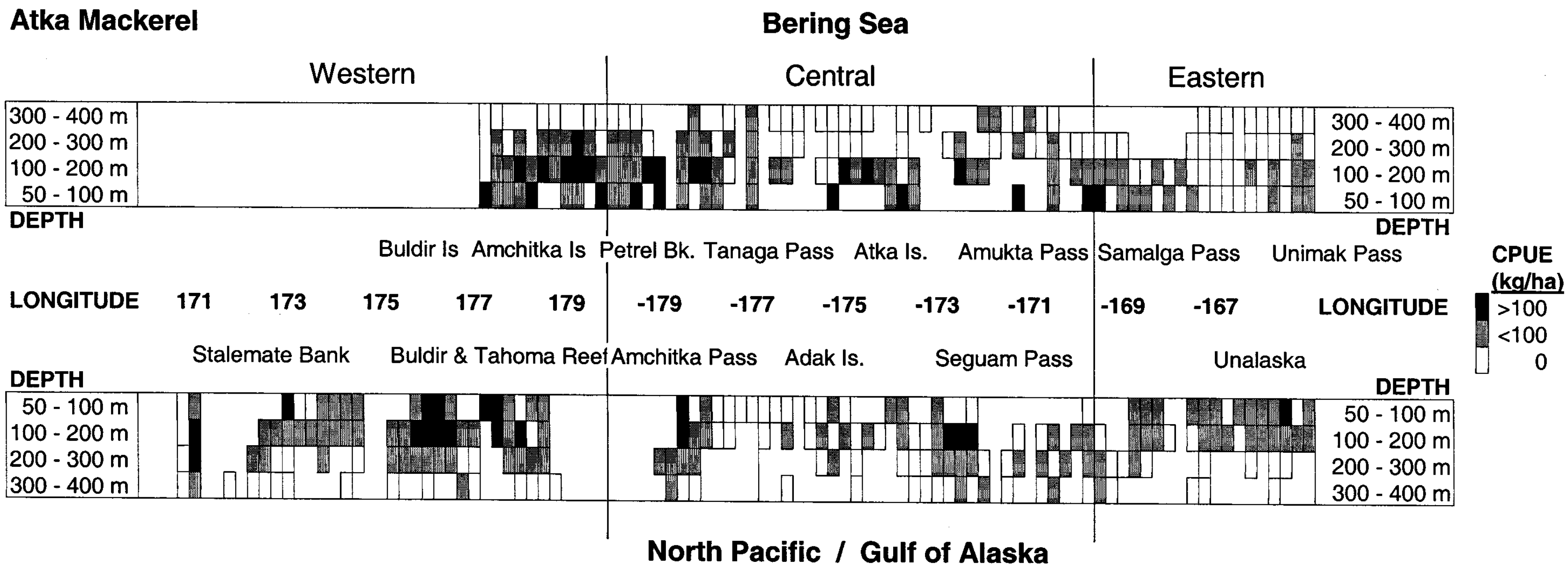


Fig. 6b

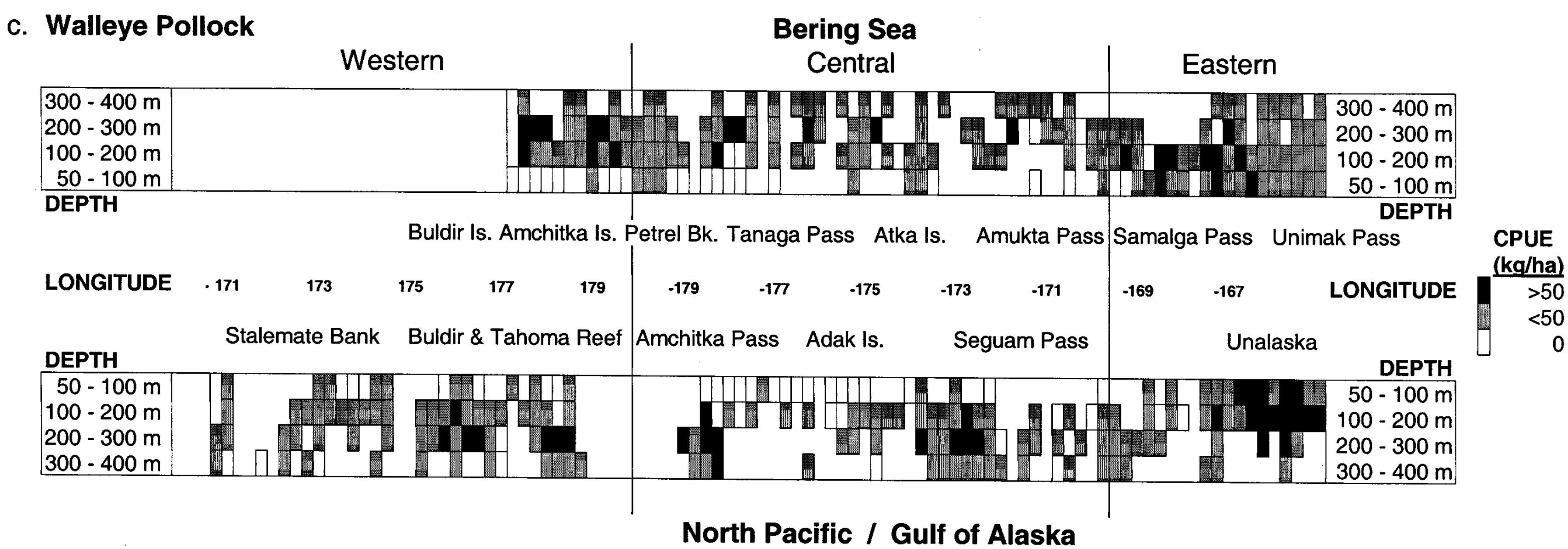
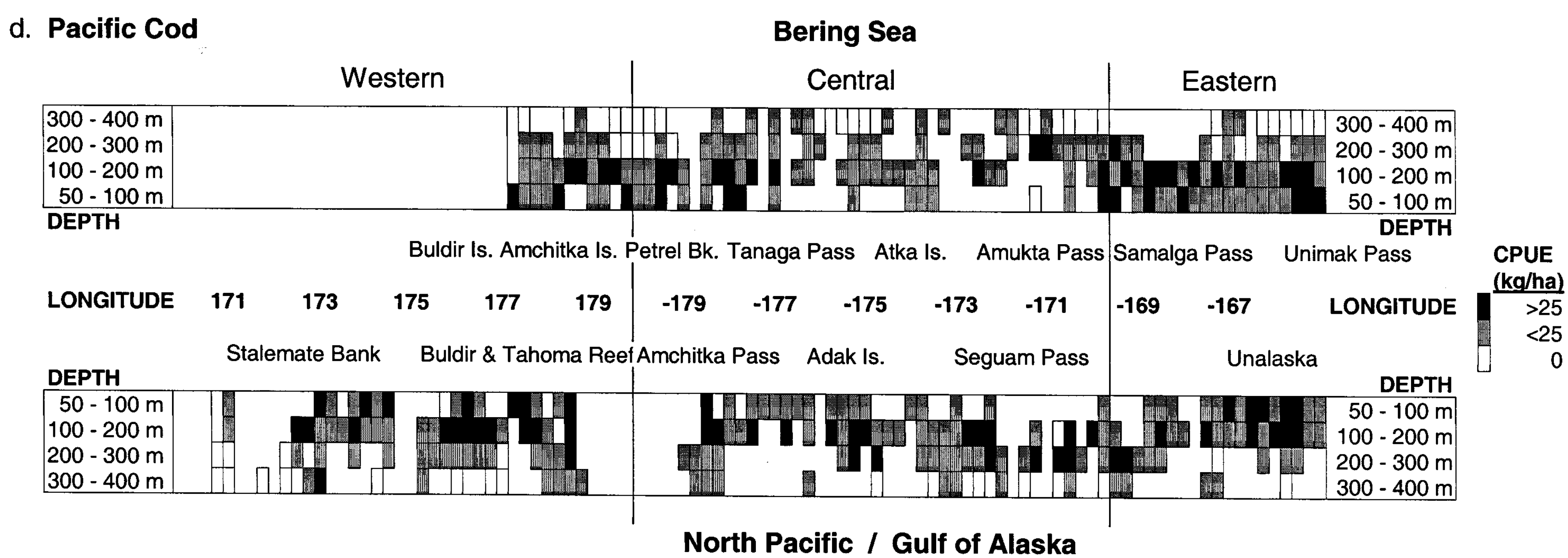
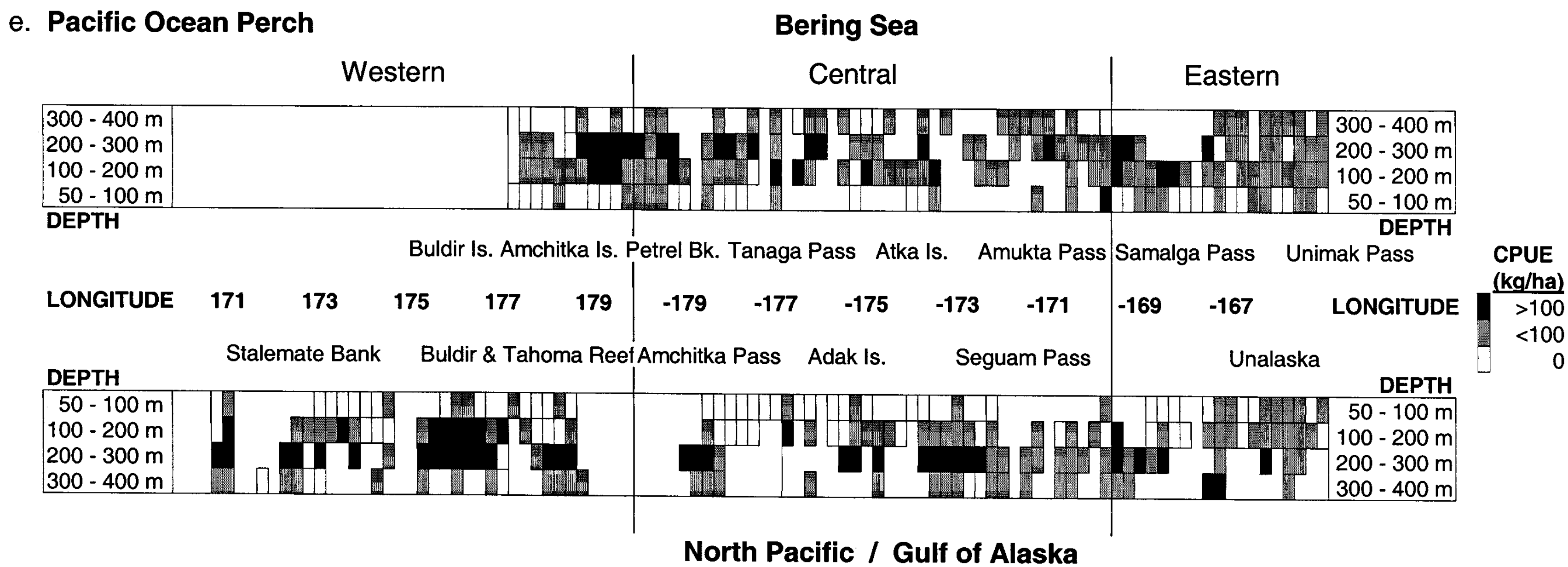

c. Walleye Pollock
Bering Sea
Western
Central
Eastern
300 - 400 m
200 - 300 m
100 - 200 m
50 - 100 m
DEPTH
Buldir Is. Amchitka Is. Petrel Bk. Tanaga Pass Atka Is. Amukta Pass Samalga Pass Unimak Pass
LONGITUDE
171 173 175 177 179 -179 -177 -175 -173 -171 -169 -167
Stalemate Bank Buldir & Tahoma Reef Amchitka Pass Adak Is. Seguam Pass Unalaska
North Pacific / Gulf of Alaska
CPUE
(kg/ha)
>50
<50
0

Fig. 6c



d. Pacific Cod
Bering Sea
Western
Central
Eastern
300 - 400 m
200 - 300 m
100 - 200 m
50 - 100 m
DEPTH
Buldir Is. Amchitka Is. Petrel Bk. Tanaga Pass Atka Is. Amukta Pass Samalga Pass Unimak Pass
LONGITUDE 171 173 175 177 179 -179 -177 -175 -173 -171 -169 -167 LONGITUDE
Stalemate Bank Buldir & Tahoma Reef Amchitka Pass Adak Is. Seguam Pass Unalaska
DEPTH
50 - 100 m
100 - 200 m
200 - 300 m
300 - 400 m
North Pacific / Gulf of Alaska
CPUE (kg/ha)
>25
<25
0

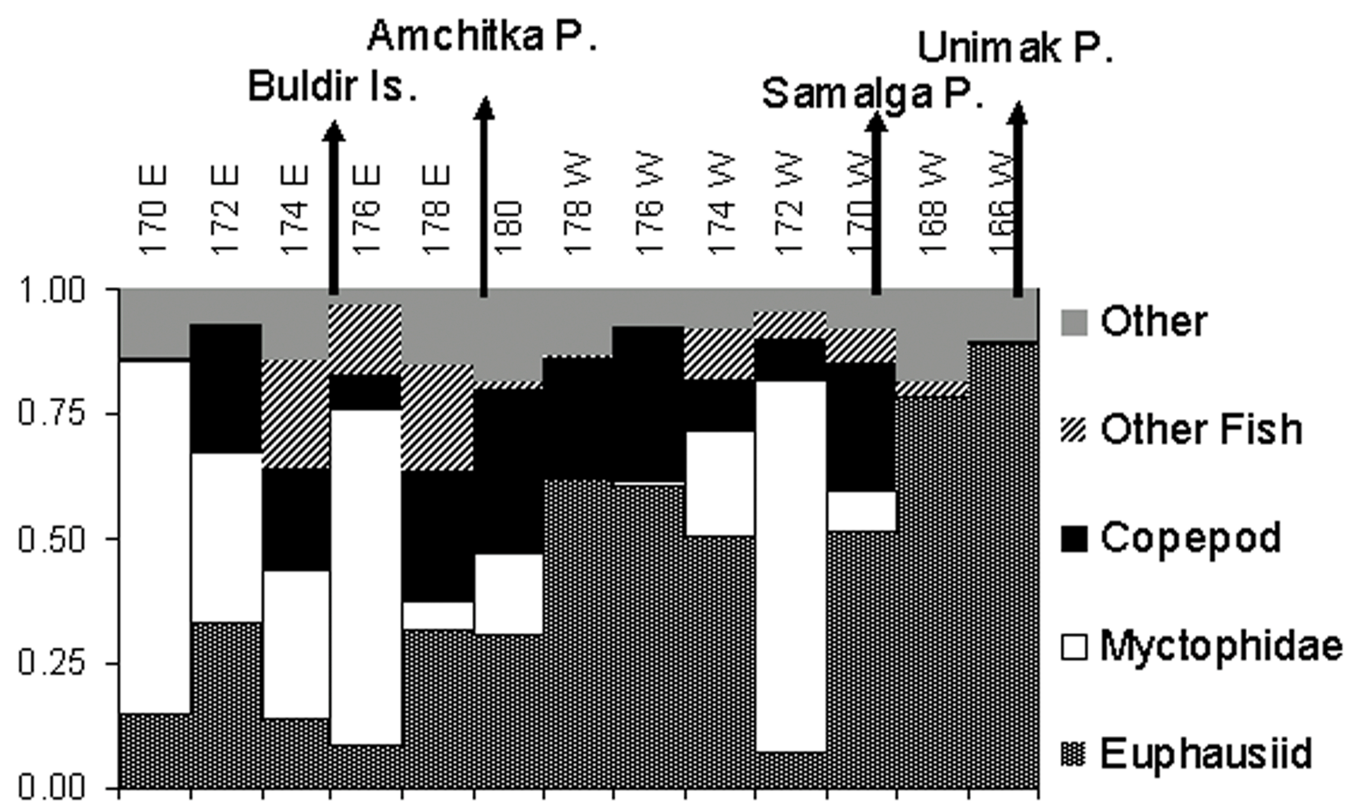
Fig. 6d



e. Pacific Ocean Perch
Bering Sea
Western
Central
Eastern
300 - 400 m
200 - 300 m
100 - 200 m
50 - 100 m
DEPTH
Buldir Is. Amchitka Is. Petrel Bk. Tanaga Pass Atka Is. Amukta Pass Samalga Pass Unimak Pass
LONGITUDE 171 173 175 177 179 -179 -177 -175 -173 -171 -169 -167 LONGITUDE
Stalemate Bank Buldir & Tahoma Reef Amchitka Pass Adak Is. Seguam Pass Unalaska
DEPTH
50 - 100 m
100 - 200 m
200 - 300 m
300 - 400 m
North Pacific / Gulf of Alaska
CPUE
(kg/ha)
>100
<100
0

Fig. 6e

a.



Amchitka P.
Buldir Is.
Unimak P.
Samalga P.
170 E
172 E
174 E
176 E
178 E
180
178 W
176 W
174 W
172 W
170 W
168 W
166 W
1.00
0.75
0.50
0.25
0.00
Other
Other Fish
Copepod
Myctophidae
Euphausiid

Fig. 7a

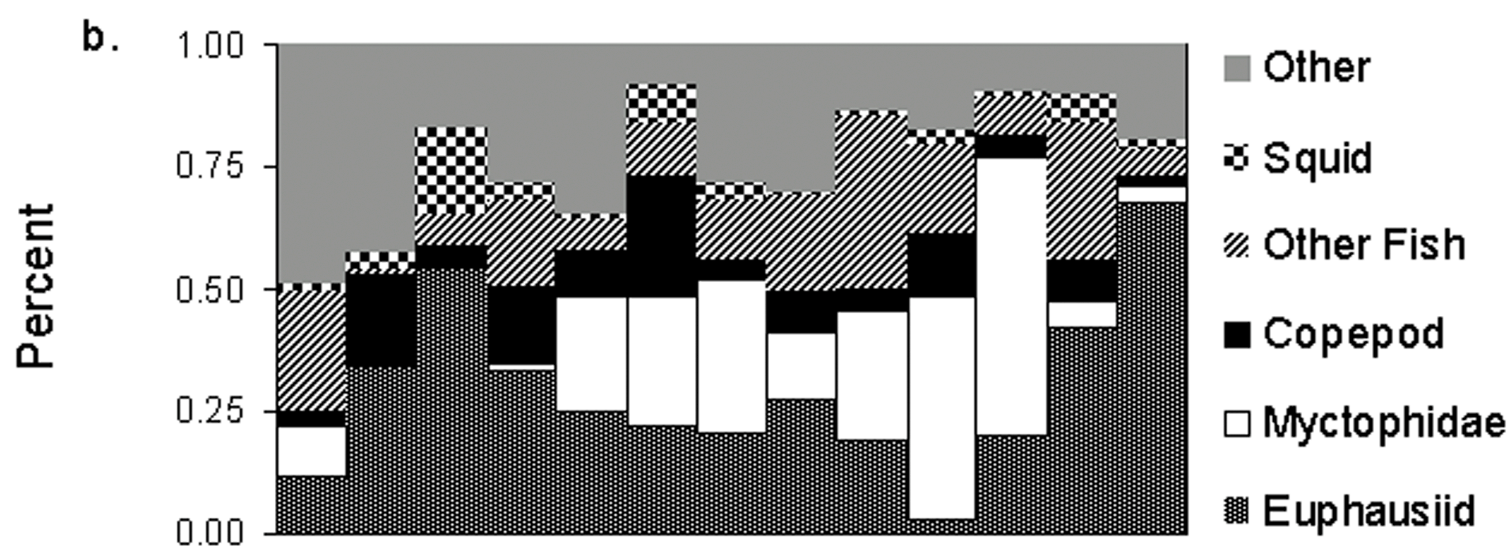

b.
Percent
1.00
0.75
0.50
0.25
0.00
Other
Squid
Other Fish
Copepod
Myctophidae
Euphausiid

Fig. 7b

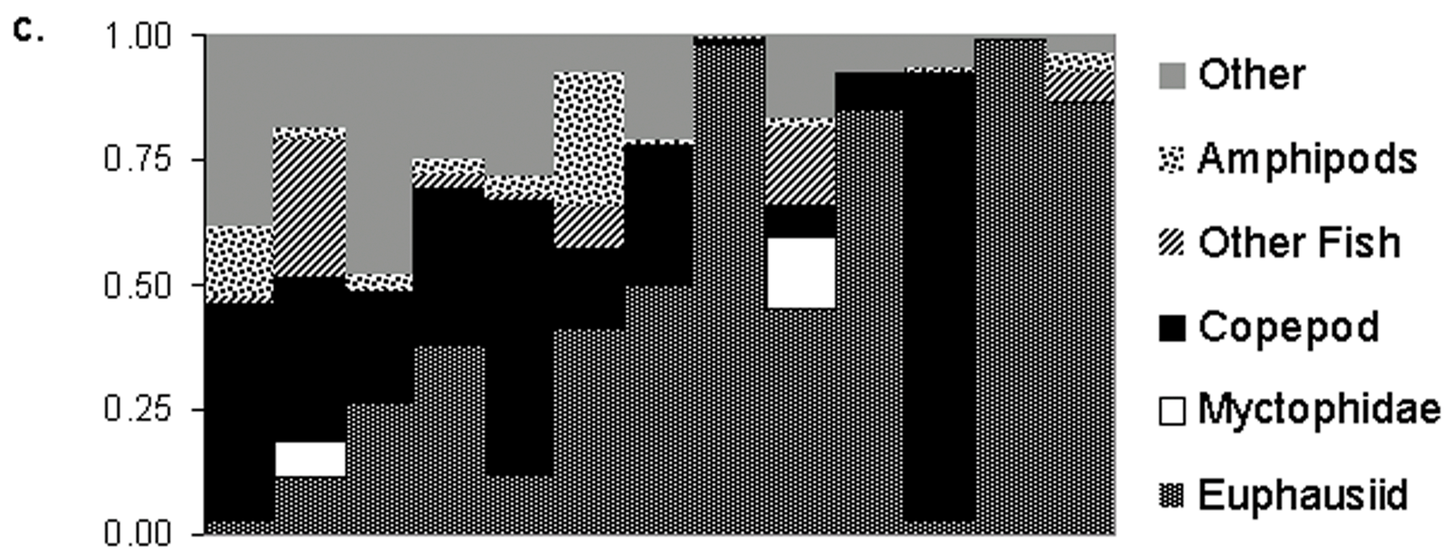

c.
1.00
0.75
0.50
0.25
0.00
Other
Amphipods
Other Fish
Copepod
Myctophidae
Euphausiid

Fig. 7c

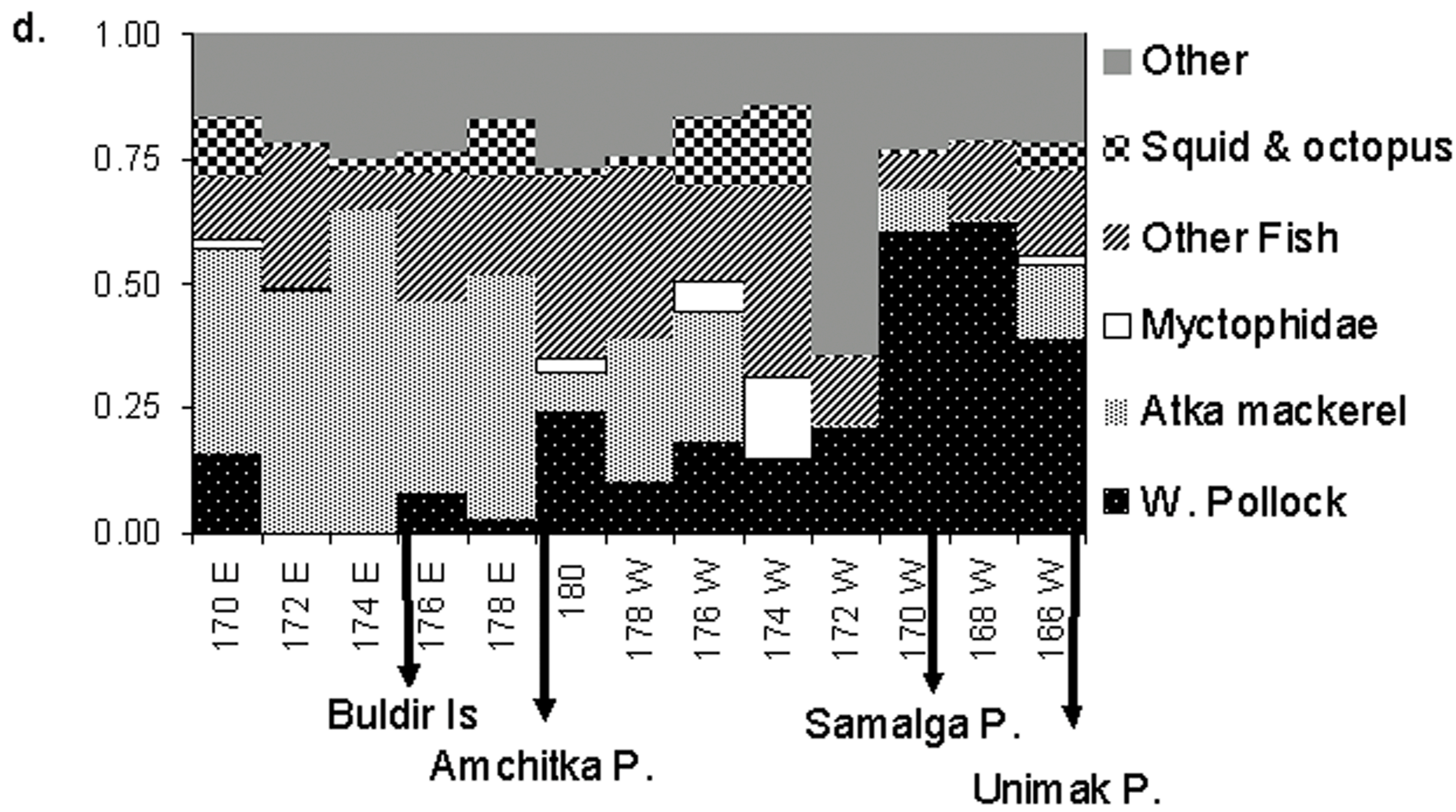

d.
1.00
0.75
0.50
0.25
0.00
Other
Squid & octopus
Other Fish
Myctophidae
Atka mackerel
W. Pollock
170 E
172 E
174 E
176 E
178 E
180
178 W
176 W
174 W
172 W
170 W
168 W
166 W
Buldir Is
Amchitka P.
Samalga P.
Unimak P.

Fig. 7d

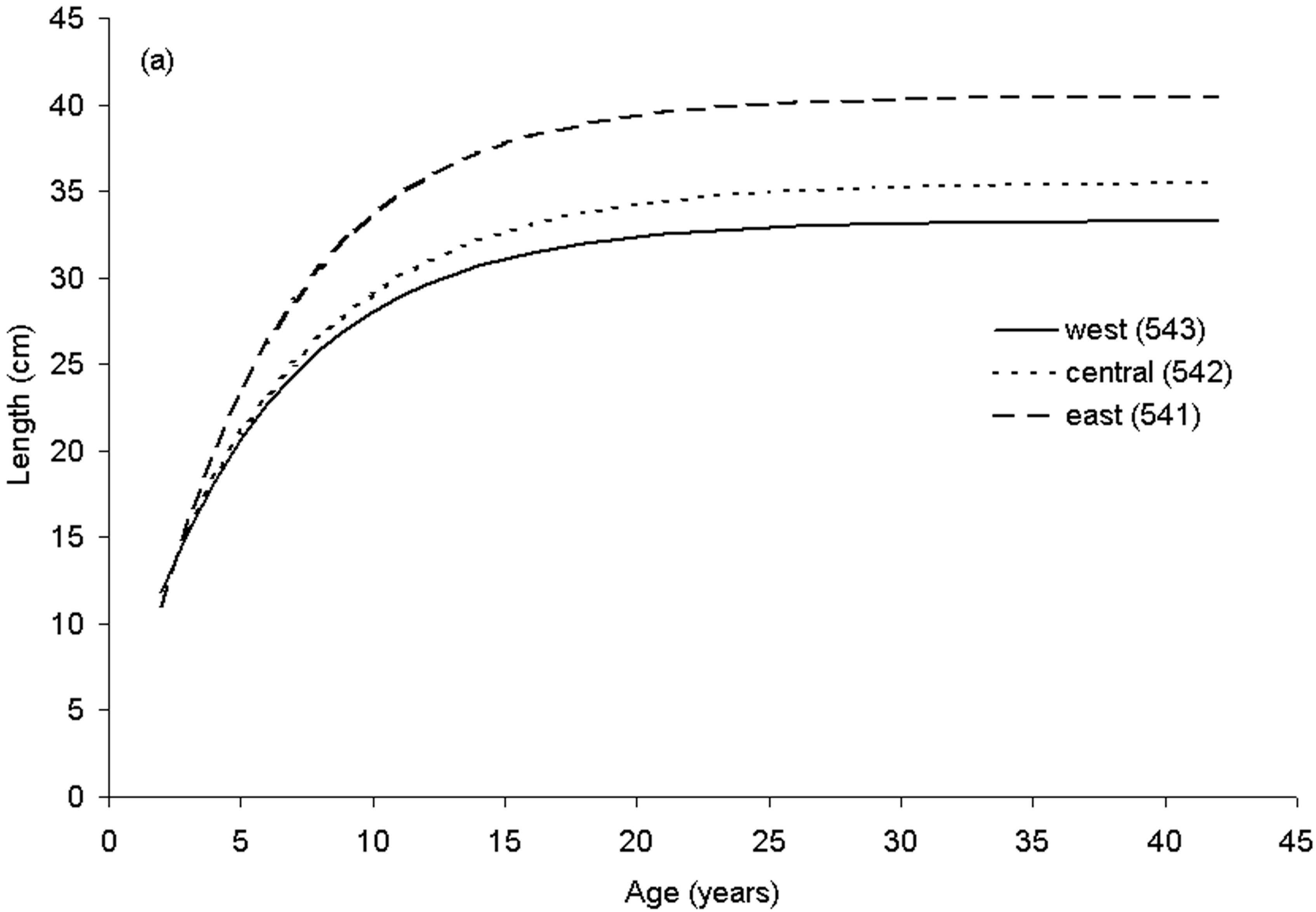

(a)
Length (cm)
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
Age (years)
west (543)
central (542)
east (541)

Fig. 8a

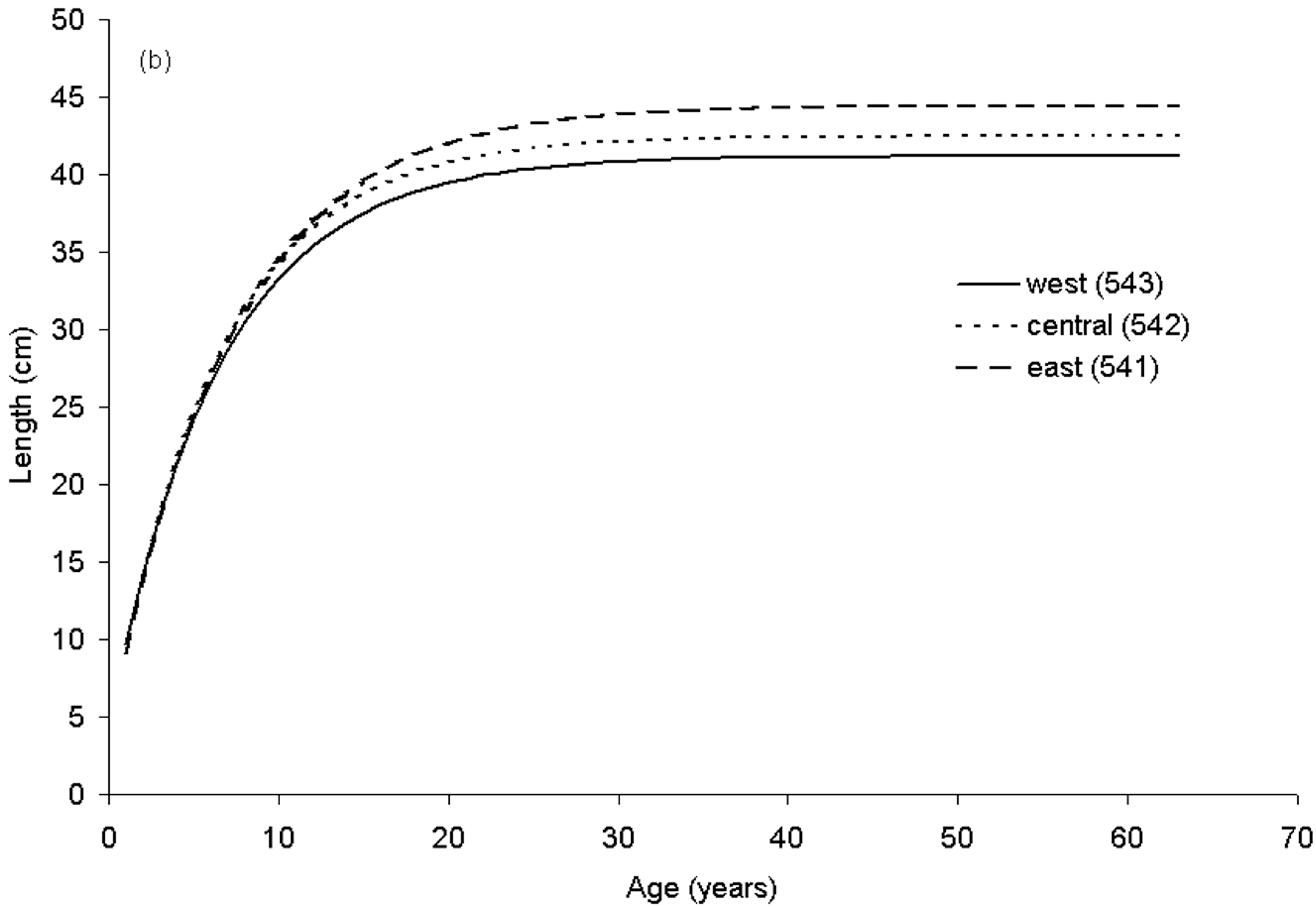

50
45
40
35
30
25
20
15
10
5
0
(b)
Length (cm)
west (543)
central (542)
east (541)
0
10
20
30
40
50
60
70
Age (years)

Fig. 8b

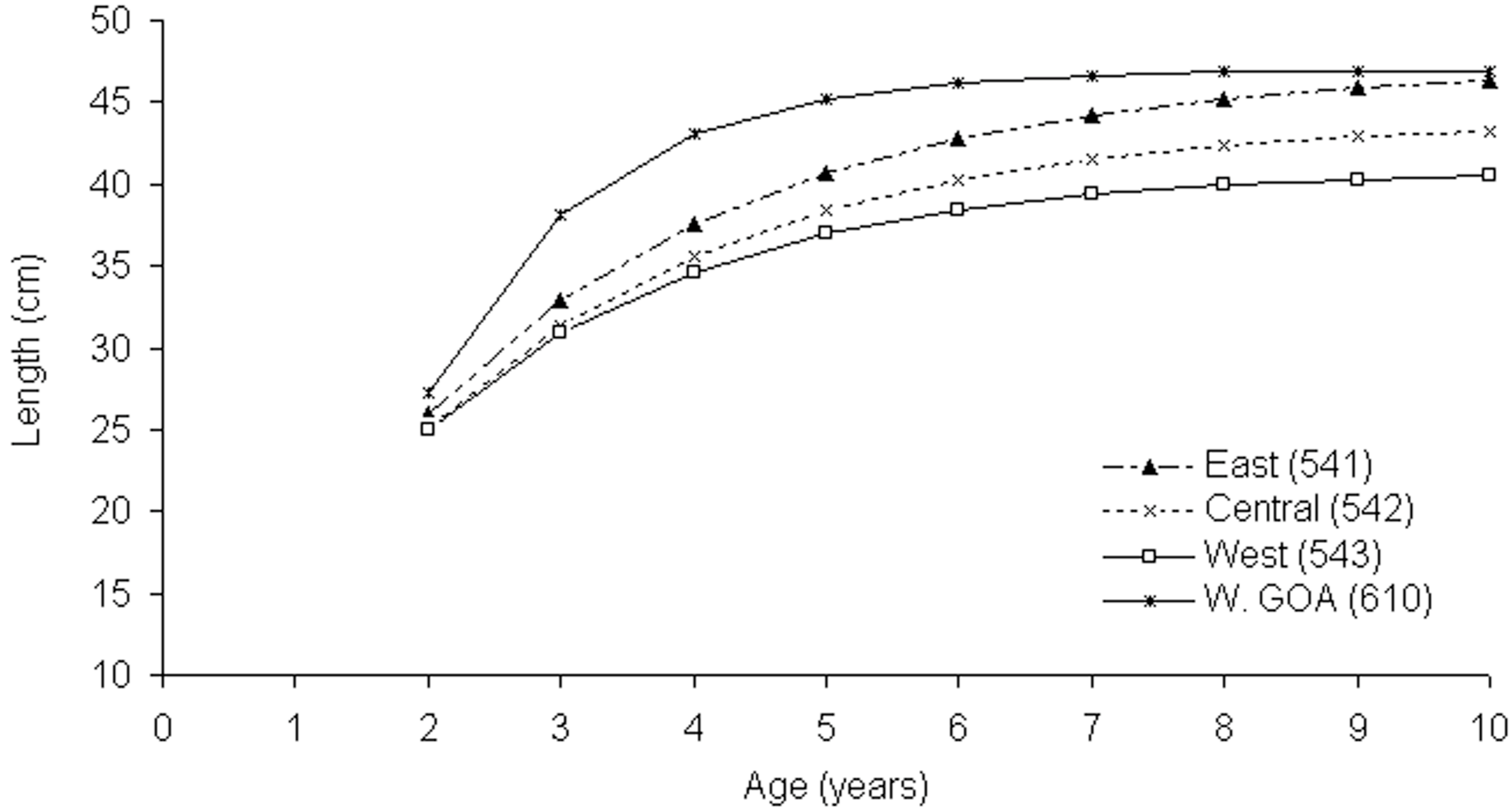

Length (cm)
50
45
40
35
30
25
20
15
10
0
1
2
3
4
5
6
7
8
9
10
Age (years)
East (541)
Central (542)
West (543)
W. GOA (610)

Fig. 9